

**US Army Corps  
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Waterways Experiment  
Station

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# **Navigation Conditions at Gray's Landing Locks and Dam, Monongahela River**

## **Hydraulic Model Investigation**

*by Ronald T. Wooley*

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Prepared for U.S. Army Engineer District, Pittsburgh

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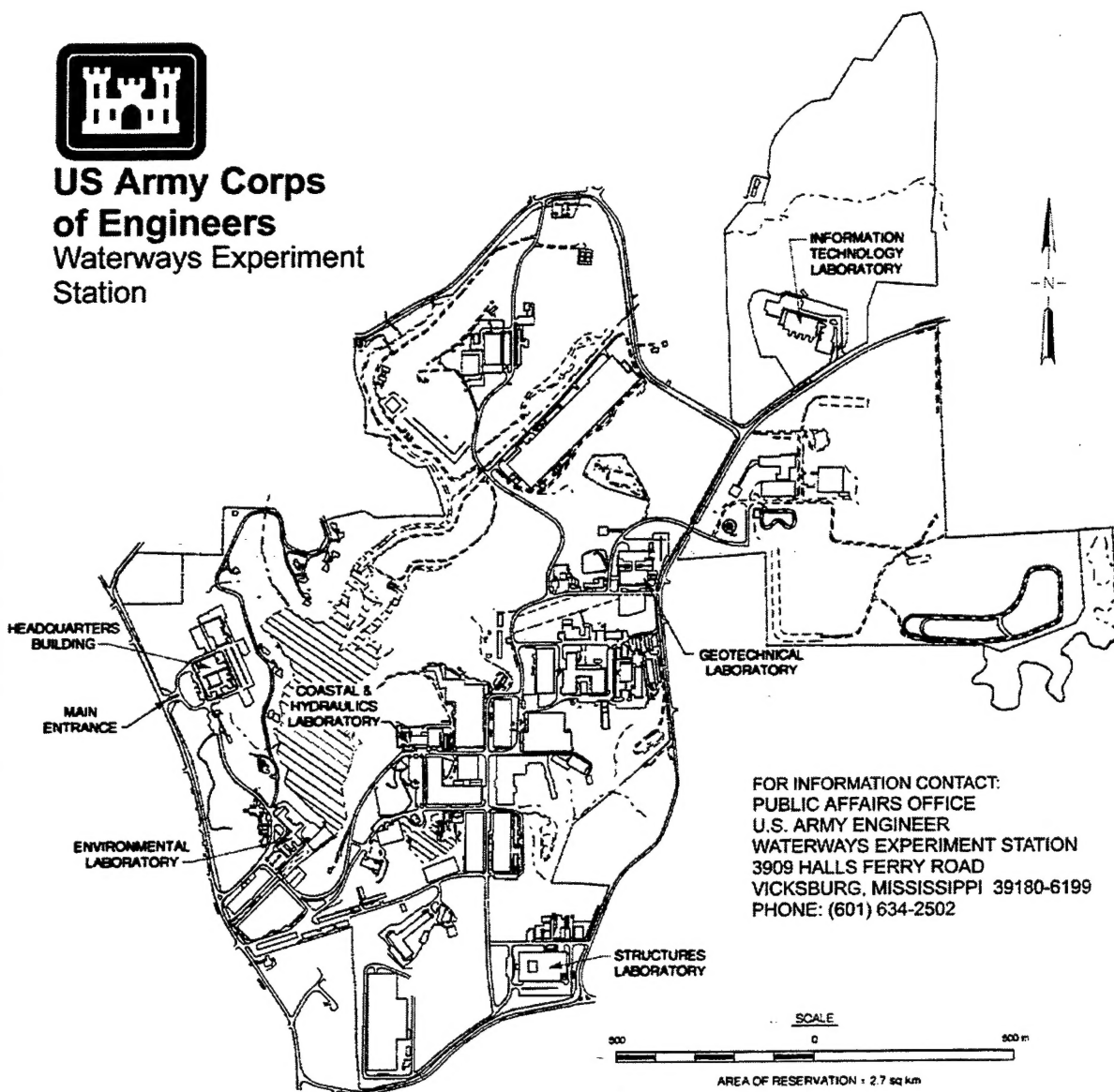
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Final report

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# Preface

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The model investigation reported herein was conducted for the U.S. Army Engineer District, Pittsburgh (ORP), by personnel of the Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station (WES), between 1985 and 1993.

During the course of the model study, representatives of ORP; the U.S. Army Engineer Division, Ohio River; Headquarters, U.S. Army Corps of Engineers; and other navigation interests visited WES at various times to observe special model experiments and to discuss the results of those experiments. ORP was informed of the progress of the study by means of monthly progress reports and special reports at the end of each experiment.

This report is being published by the WES Coastal and Hydraulics Laboratory (CHL). The CHL was formed in October 1996 with the merger of the WES Coastal Engineering Research Center and the Hydraulics Laboratory. Dr. James R. Houston is the Director of the CHL, and Mr. Charles C. Calhoun, Jr., is Assistant Director.

The first line review of this report was conducted by Dr. Sandra K. Martin, Acting Chief of CHL's Navigation Branch. The principal investigator in immediate charge of the model study was Mr. R. T. Wooley, assisted by Messrs. E. Johnson, E.A. Frost, and J. W. Sullivan, and Ms. D. P. George. This report was prepared by Mr. Wooley.

Director of WES during preparation and publication of this report was Dr. Robert W. Whalin. Commander was COL Robin R. Cababa, EN.

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# Conversion Factors, Non-SI to SI Units of Measurement

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Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic meters per second
degree (angle)	0.01745329	radians
feet	0.3048	meters
feet per second	0.3048	meters per second
miles (U.S. statute)	1.609344	kilometers
square miles	2,589,998.0	square meters

# 1 Introduction

---

## Location and Description of Prototype

The Monongahela River (Figure 1) is formed by the confluence of the Tygart Valley and West Fork Rivers at Fairmont, WV, and flows in a northerly direction joining with the Allegheny River at Pittsburgh, PA, to form the Ohio River. The river drains an area of 7,386 square miles<sup>1</sup> and drops a total of 147 ft in its 128.7-mile length.

Gray's Landing Lock and Dam is a proposed replacement structure for existing Lock and Dam 7 on the Monongahela River. The new lock and dam will be located near the mid-point of a mile-long straight reach of the river at about mile 82.2 in the vicinity of Gray's Landing, PA, and about 2.8 miles downstream of the existing Lock and Dam 7. The new lock and dam will establish an upper pool at el 778.0 that will extend about 8.6 miles upstream to Dam 8 (which has been renamed Point Marion Lock and Dam) and is in the vicinity of Point Marion, PA.

## History of Navigation Improvements on the Monongahela River

The original navigation system on the Monongahela River consisted of seven locks and dams extending upstream to Greensboro, PA. The system was reconstructed between 1902 and 1932, resulting in 15 navigation structures from Pittsburgh, PA, to Fairmont. Starting in 1950, redevelopment of the Monongahela replaced Locks and Dams 10 and 11 with a single structure at Morgantown, WV; replaced Locks and Dams 12, 13, 14, and 15 with the Hildebrand and Opkiska projects; permitted Lock and Dam 5 to be removed with the construction of a new Dam 4; and replaced Dam 6 with Maxwell Lock and Dam. Structures still unimproved include Locks and Dams 2, 3, 7, and 8 and Lock 4.

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<sup>1</sup> A table of factors for converting non-SI units of measurement to SI units is presented on page vi.

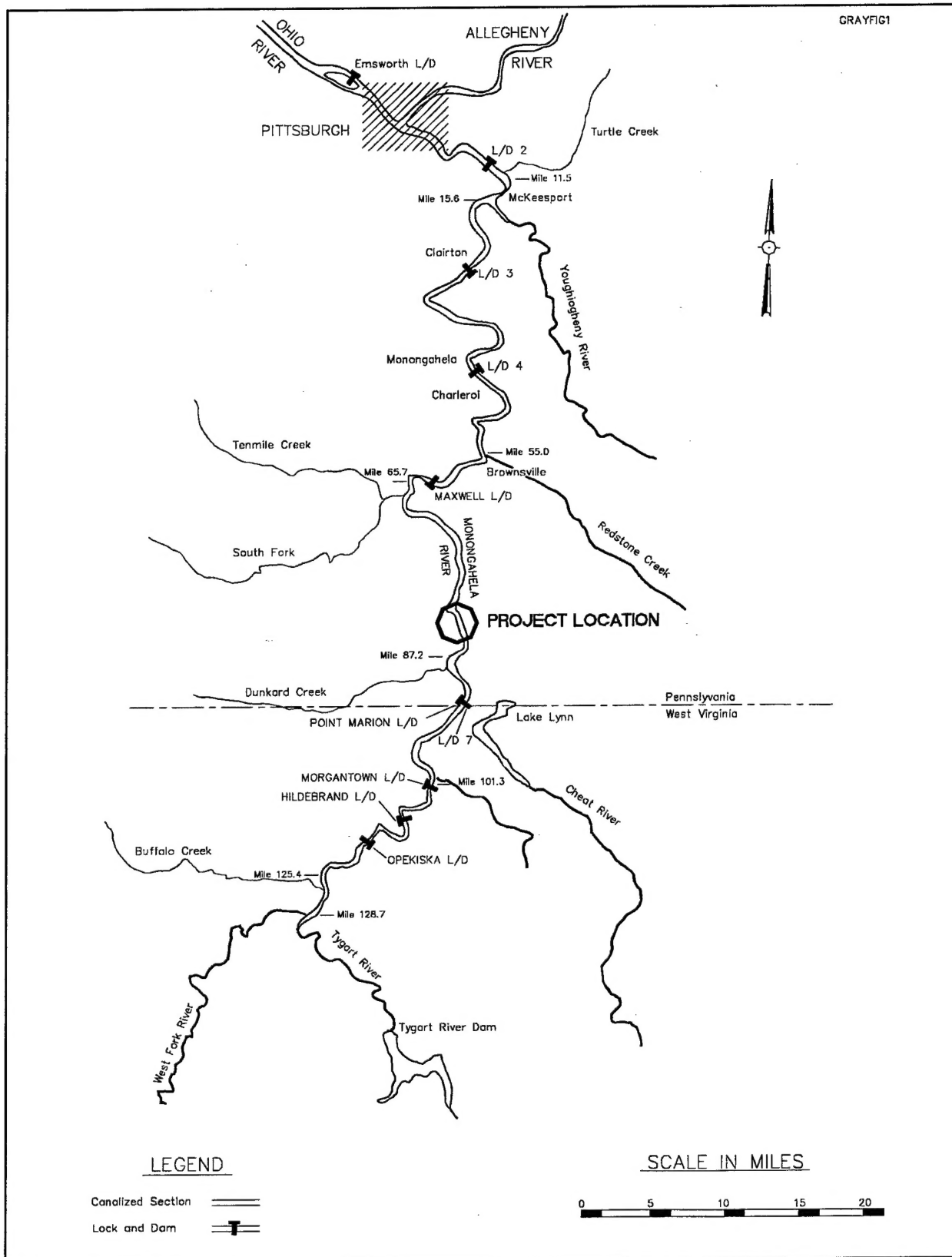


Figure 1. Location map

## **Present Development Plan**

To maintain navigation on the 40 miles of river between Maxwell and Morgantown Locks and Dams it is proposed to construct a new lock landward of the existing Lock 8 and construct a new lock and dam at river mile 82.2 in the vicinity of Gray's Landing, PA, which would replace the existing Lock and Dam 7. The new structure at Gray's Landing will consist of an 84-ft-wide by 720-ft-long lock located along the right descending bank and a fixed crest dam.

## **Purpose of Model Study**

The general design of the new lock and dam at Gray's Landing was based on sound theoretical design practice and experience with similar structures. However, navigation conditions vary with location and flow conditions upstream and downstream of a structure, and an analytical study to determine the hydraulic effects that can reasonably be expected to result from a particular design is both difficult and inconclusive. Since the new lock and dam were to be located downstream of a bend in the river, it was important that the position of the lock and the design of the guard wall provide satisfactory current patterns for navigation. Therefore, a comprehensive model study was considered necessary to investigate conditions that could be expected with the proposed design and to develop modifications required to ensure satisfactory navigation conditions. The specific purposes of the model study were to:

- a. Investigate the proposed location for the new lock and dam.
- b. Determine optimum channel alignment and channel training structures required.
- c. Determine modifications required to provide satisfactory navigation conditions.
- d. Investigate the effects of the completed project, first-stage cofferdam, and second-stage cofferdam on water-surface slopes through the reach.
- e. Evaluate navigation conditions during construction of the project and develop any modifications required to improve navigation conditions.
- f. Demonstrate to navigation interests the conditions resulting from the proposed design and satisfy these interests of the design's acceptability from a navigation standpoint.
- g. Design a guard wall that would provide satisfactory navigation conditions.
- h. Demonstrate to navigation interests conditions that could exist during construction of the new lock and dam.

## 2 The Model

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### Description

The scale model reproduced about 2.1 miles of the Monongahela River channel and adjacent overbank, from mile 81.0 to mile 83.1, with lock and dam structures. The model was of the fixed-bed type with overbank areas and channel molded of sand cement mortar to sheet metal templates set to the proper grade. Portions of the model where changes in bank alignments and channel configurations could be anticipated were molded of pea gravel to facilitate modifications necessary to develop satisfactory navigation conditions. The lock, guide walls, guard wall, and fixed-crest spillway were constructed of sheet metal and set at the proper grade. The channel portion of the model was molded to conform to a hydrographic survey dated May 1966, and the overbank was molded to a topographic survey dated May 1961. The model limits were constructed to a grade sufficient to confine the 500-year frequency flood (197,000 cfs).

### Scale Relations

The model was built to an undistorted scale of 1:100, model to prototype, to effect accurate reproduction of velocities, crosscurrents, and eddies affecting navigation. Other scale ratios resulting from the linear scale ratio are as follows:

Characteristic	Units of Length	Model:Prototype
Area	$A =$	1:10,000
Velocity	$V =$	1:10
Time	$T =$	1:10
Discharge	$D =$	1:100,000
Roughness (Manning's $n$ )	Manning's $n =$	1:2.15

Measurements of discharges, water-surface elevations, and current velocities can be transferred quantitatively from model to prototype equivalents by means of these relations.



## Appurtenances

Water was supplied to the model by means of a 10-cfs pump operating in a recirculating system. The discharge was controlled and measured at the upper end of the model by means of a valve and venturi meter. Water-surface elevations were measured by means of piezometer gauges located in the model channel and connected to a centrally located gauge pit (Figure 2). A slide-type tailgate was provided at the lower end of the model to control the tailwater elevation downstream of the dam, and the upper pool elevation was naturally controlled by the fixed crest dam.

Velocities and current directions were measured in the model by cylindrical wooden floats submerged to the depth of a loaded barge (9-ft prototype). Confetti and dye were also used to determine current patterns in eddies. A miniature current meter measured spot velocities. A radio-controlled model tow and towboat, equipped with twin screws, Kort nozzles, and forward and reverse rudders, and powered by a small electric motor operating from batteries in the tow, were used to study and demonstrate the effects of currents on navigation. The tow in the study represented six 195-ft-long by 35-ft-wide standard barges with a 100-ft-long pusher. This provided a tow with an overall size of 685 ft (length) by 70 ft (width) loaded to a draft of 9 ft. The towboat operated in forward and reverse, at various speeds, and with variable rudder settings. It was calibrated to the speed of a comparable size prototype towboat moving in slack water and operated at 1 to 2 miles per hour above the speed of the currents to maintain rudder control but not overpower the currents. Multiple-exposure photographs recorded the path of the tow with the various conditions (Figure 3).

## Model Adjustment

Inclusion of the proposed lock and dam in the initial model construction precluded adjustment of the model to existing conditions. This type of adjustment was not considered necessary since the proposed improvements would involve considerable change from existing conditions. The model was constructed with a brushed-cement mortar finish to provide a roughness factor (Manning's  $n$ ) of about 0.0135, which corresponds to a prototype of about 0.029. Based on experience with other models of this type, brushed concrete gives a close approximation of the roughness required to reproduce prototype conditions.

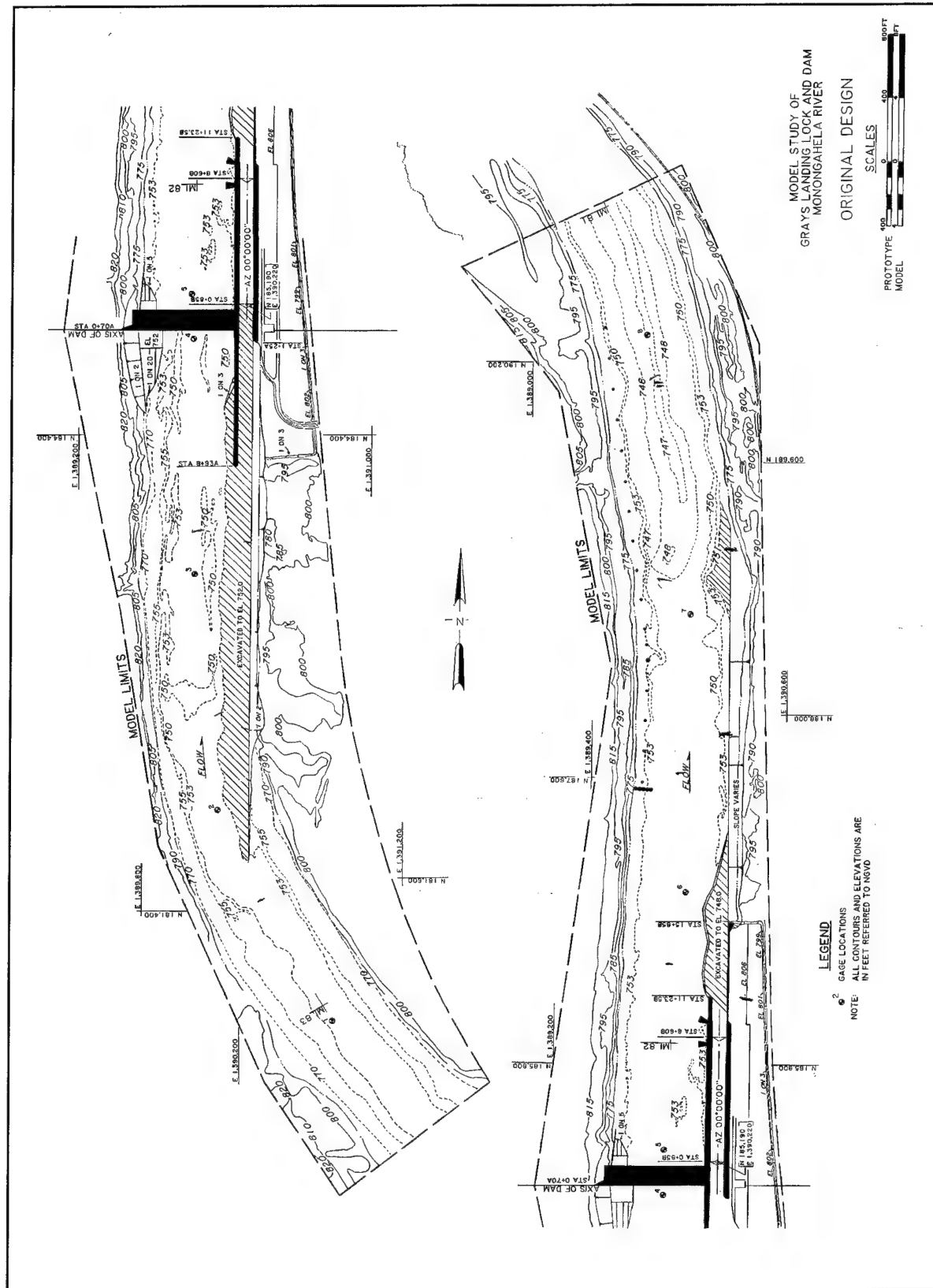


Figure 2. Model layout

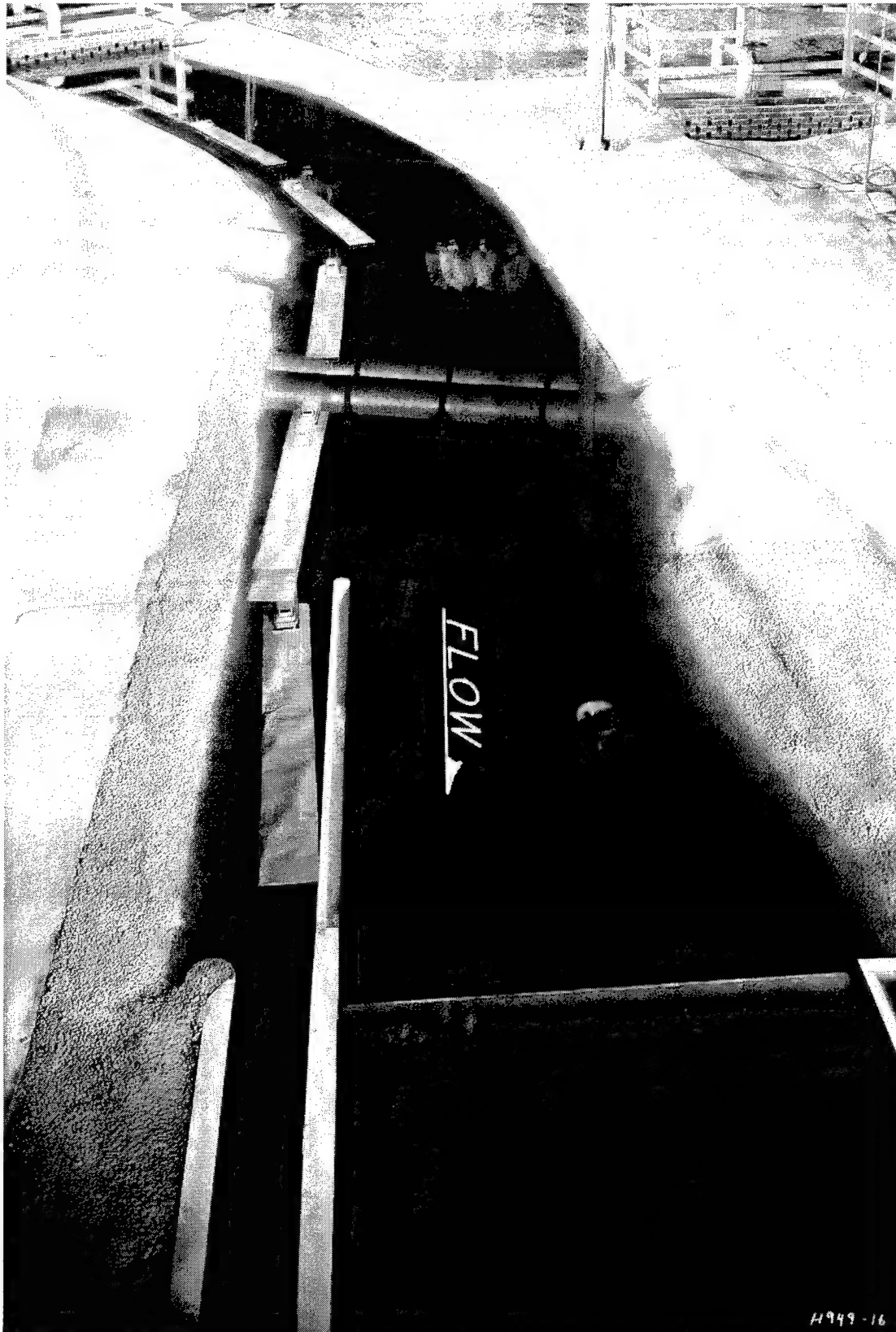


Figure 3. Path of tow with various conditions

# 3 Experiments and Results

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Experiments were concerned primarily with the study of flow patterns, measurements of velocities and water-surface elevations, and the effects of currents on the movement of the model tow into the lock approaches during navigable riverflows. Many of the modifications were developed during preliminary experiments. Data obtained during these experiments were sufficient to assist in the development of the plan that appeared to provide satisfactory results. Results of the preliminary experiments are not included in this report.

## Experiment Procedures

A selection of representative riverflows were used for the experiments, based on information furnished by the Pittsburgh District, as follows:

- a.* 51,800-cfs riverflow with tailwater el 775.0.
- b.* 73,000-cfs riverflow with tailwater el 779.3.
- c.* 102,000-cfs riverflow with tailwater el 784.5.
- d.* 107,500-cfs riverflow with tailwater el 785.6 (Maximum Navigable).
- e.* 123,500-cfs riverflow with tailwater el 788.3.
- f.* 157,000-cfs riverflow with tailwater el 793.3.
- g.* 168,000-cfs riverflow with tailwater el 794.7.
- h.* 197,000-cfs riverflow with tailwater el 798.8.

During the base experiments, the tailwater elevation was controlled at Gauge 5 to a tailwater-versus-discharge rating curve developed by the Pittsburgh District. For subsequent experiments, the tailwater was controlled at Gauge 8 to elevations obtained during the base experiments.

## Base Experiments with Original Design

### Description

Base experiments were conducted with the model reproducing the original design, as shown in Figure 2. The principal features reproduced or simulated in the model, as shown in Figures 2 and 4, included:

- a. A navigation lock with clear chamber dimensions of 84 ft (width) and 720 ft (length) constructed on the right descending bank. The tops of the lock walls were at el 792.5.
- b. A 735.73-ft-long ported guard wall with seventeen 25.46-ft-diam cells spaced 40 ft on centers with top el 778.0 (Figure 4). The nose cell at the upstream end of the guard wall was a 26.46-ft-diam cell and a half cell joined the guard wall with the lock wall. The cells were capped with a solid concrete member that extended from the upstream end of the wall to the lock wall. The top of the concrete cap was at the same elevation as the top of the lock (el 792.5) and the bottom of the cap was at el 778.0. This provides eighteen 14.54-ft-wide port openings with top of ports at el 778.0. The concrete cap extended 1.0 ft landward of the cells to align with the lock chamber and provide a rubbing surface for tows that extended beyond the cells.
- c. A 725-ft-long solid lower guide wall extending downstream from the landside lock wall with top el 792.5. The effective length of the guide wall measured from the downstream end of the riverside lock wall is 461.5 ft.
- d. The right bank upstream of the lock was excavated to el 752.0 along a line extending from the inside face of the landside lock wall to a point about 3,200 ft upstream of the lock wall. The excavation tied into the natural contours of the riverbed both riverward of the lock and at the upstream end of the excavation. The bank slope of the excavation was 1V on 2H.
- e. The lower approach of the lock was excavated to el 748.0 and the right bank was realigned to provide a straight bank from the downstream end of the landside guide wall to a point about 2,400 ft downstream of the guide wall or about 4,000 ft downstream of the dam. The bank slope of the excavation varied to tie into the natural contours.
- f. A 576.08-ft-long fixed crest overflow weir extended across the river channel from the lock to the left bank. The crest of the weir was at el 778.0. The weir was connected to the left bank with a 15-ft-wide abutment and a 45-ft-long by 10-ft-wide non-overflow weir with top at el 795.



## Results

**Water-surface elevations.** Water-surface elevations obtained with the original design are shown in Table 1. These data show the slope in water surface elevations varied from about 0.1 to 0.4 ft per mile upstream of the dam and from about 0.7 to 1.1 ft per mile downstream of the dam with the 51,800- and 123,500-cfs riverflows, respectively. When flow overtopped the lock walls (el 792.5), the slope in water-surface elevations upstream and downstream of the dam decreased. The drop across the dam varied from about 11.5 to 3.2 ft with the 51,800- and 197,000-cfs riverflows, respectively.

**Current directions and velocities.** Current directions and velocities obtained with the original design are shown in Plates 1-3. Photos 1-4 depict current patterns with confetti. These data show the currents are generally parallel with the right bank from the upstream end of the model to a point about 2,500 ft upstream of the dam, where the flow tends to separate from the right bank and follow the old river channel. A small clockwise eddy formed near the upstream end of the excavation where the right bank of the excavation ties into the natural riverbank. The flow moves across the fixed-crest weir, follows the riverside of the lock to its downstream end, and then moves across the lower approach of the lock to become parallel with the right bank about 800 ft downstream of the lower end of the guide wall. A large clockwise eddy formed in the lower approach of the lock and the upstream velocities ranged from about 0.9 to 1.8 fps with the 51,800- and 107,500-cfs riverflows, respectively. The velocity of the currents that would affect a tow navigating the reach upstream of the dam ranged from about 3.0 to 5.2 fps near the upstream end of the model, 3.5- to 6.1-fps about 2,500 ft upstream of the dam, and 2.9 to 4.3 fps near the upstream end of the guard wall with the 51,800- and 107,500-cfs riverflows, respectively. The velocity of the currents downstream of the dam ranged from about 5.9 to 8.0 fps opposite the downstream end of the guide wall, 6.0 to 8.2 fps about 4,000 ft downstream of the dam, and 5.1 to 7.1 fps near the downstream end of the model with the 51,800- and 107,500-cfs riverflows, respectively.

**Navigation conditions.** Navigation conditions upstream of the dam were less than satisfactory with the 51,800-cfs riverflow, and as the riverflow increased to 107,500-cfs, navigation conditions became hazardous for downbound tows approaching the lock. With the 51,800-cfs riverflow, downbound tows could enter the modeled reach along the right bank, start a flanking maneuver near the upstream end of the excavation to move the tow into the excavation and align with the right bank, drive along the right bank to a point about one-half of a tow length upstream of the guard wall, and approach the guard wall at a safe speed (Photo 4). This type of approach could require considerable time and maneuvering. A downbound tow driving the reach was unable to make the turn into the excavated channel and align with the guard wall (Photo 5). Upbound tows could move away from the guard wall and navigate upstream without any major difficulties with all riverflows evaluated (Photo 6).

Navigation conditions were satisfactory for tows entering and leaving the lower lock approach with all riverflows evaluated. Downbound tows could

move the head of the tow away from the guide wall, drive away from the right bank and navigate through the reach without any major difficulties (Photos 7 and 8). There was one area along the right bank about 3,600 ft downstream of the lock that did not provide navigation depth. Therefore, tows were required to drive riverward to avoid the area. Upbound tows could approach the lock and land the head of the tow on the guide wall, align with the lock chamber, and push in without any major difficulties (Photos 9 and 10). With the higher riverflows, an upbound tow was required to take a set riverward as it approached the guide wall to counteract the currents moving across the approach toward the right bank (Photo 10). An upbound tow did not have any difficulties holding the head of the tow on the guide wall as it pushed into the lock chamber.

## **Experiments with Original Design - Modified**

### **Description**

The modified original design (Figure 5) was the same as the original design, except five submerged groins spaced about 300 ft apart were placed along the right bank. The first dike upstream of the lock was about 1,000 ft upstream of the upstream end of the guard and the most upstream dike was about 2,200 ft upstream of the guard wall. The tops of the dikes were at el 766.0, which provided about 12 ft of depth over the dikes at minimum upper pool el 778.0. A table showing the location, alignment, and elevation of the dikes is included in Figure 5.

### **Results**

**Water-surface elevations.** Water-surface elevations obtained with the modified original design are shown in Table 2. These data indicate the slope in water-surface elevations and the drop across the dam were generally the same as with the original design. There were some minor locale differences in water-surface elevations due to the submerged dikes.

**Current directions and velocities.** Current directions and velocities obtained with the modified original design are shown in Plate 4. Photo 11 shows the current pattern in the upper lock approach with the 51,800-cfs riverflow. These data indicate the submerged dikes improved the alignment of the currents along the right bank approaching the lock. The currents were generally parallel with the right bank from the upstream end of the model to the lock. The submerged dikes tended to reduce the velocities of the current approaching the lock somewhat. The velocity of the currents that would affect tows navigating the reach upstream of the dam varied from about 3.2 to 5.3 fps near the upstream end of the model, 3.2 to 5.9 fps about 2,500 ft upstream of the dam, and 1.5 to 3.0 fps near the upstream end of the guard wall with the 51,800- and 107,500-cfs riverflows, respectively.





**Navigation conditions.** Navigation conditions were generally the same as with the original design. With the lower riverflow, a downbound tow could start flanking upstream of the right bank excavation, move the tow into the excavation and align with the right bank, drive along the bank to a point about one tow length upstream of the guard, and start reducing speed to approach the guard wall at a safe speed. A downbound tow driving the reach could not make the turn into the excavation and align with the guard wall a safe distance upstream of the wall.

## Experiments with Plan A

### Description

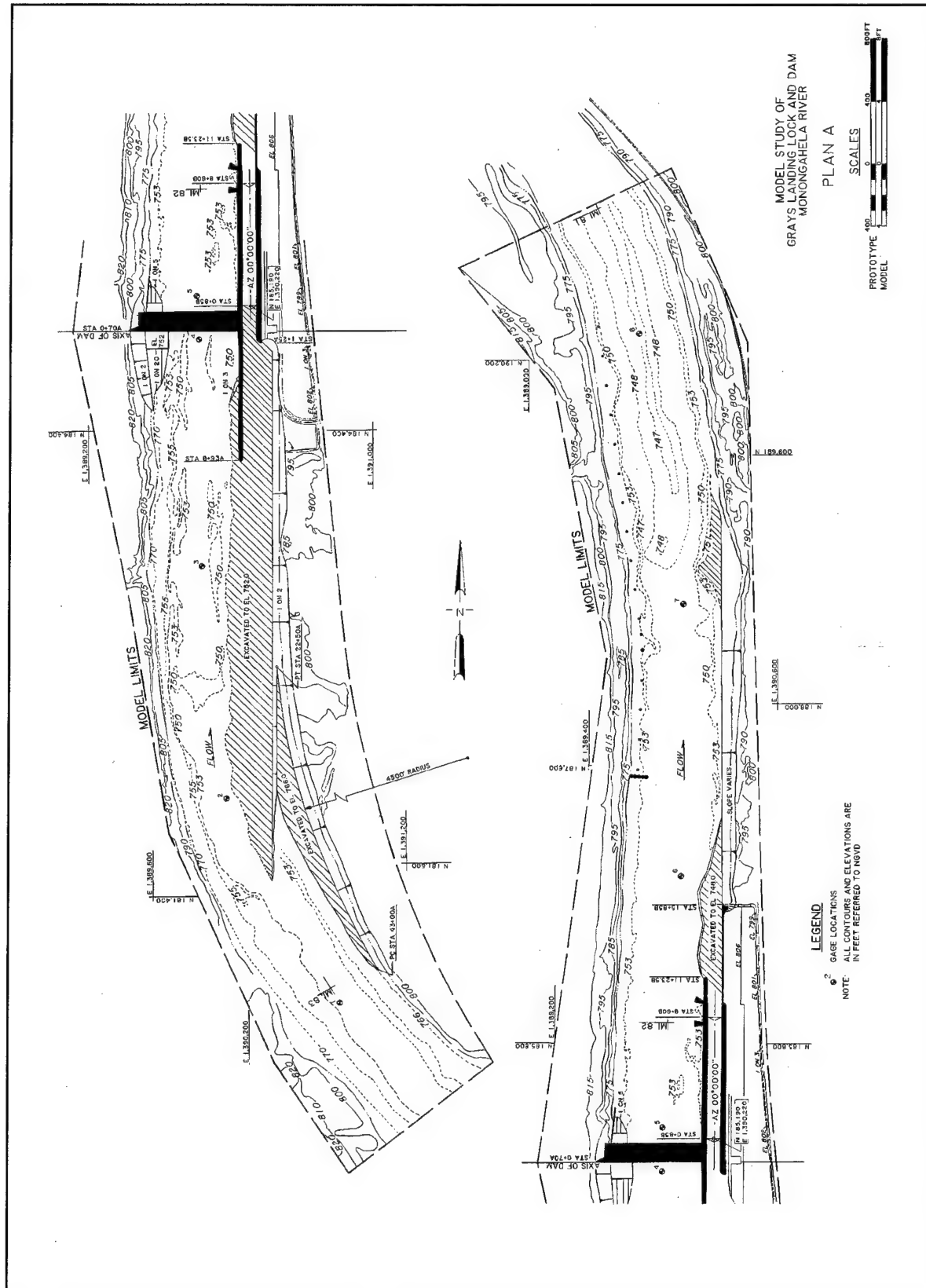
Plan A (Figure 6) was the same as the original design, except the right bank of the excavation upstream of the lock was modified to provide additional channel width landward of the guard wall. The toe of the excavation was 200 ft landward of the guard wall and extended upstream parallel with the guard wall to tie into the natural river channel. The excavation was at el 752.0. From Sta 22+50A, an additional excavation extended upstream along a 4,500-ft radius curve to Sta 43+00A at el 766.0 to provide a transition from the natural river channel into the excavated channel approaching the lock. The right bank was excavated to a 1V on 2H slope. The model downstream of the dam was the same as with the original design.

### Results

**Water-surface elevations.** Water-surface elevations obtained with Plan A are shown in Table 3. These data show the slope in water-surface elevations and the drop across the dam were generally the same as with the original design. There were some minor differences in water-surface elevations at Gauges 1 - 3 due to the increase in the right bank excavation.

**Current directions and velocities.** Current directions and velocities obtained with Plan A are shown in Plate 5. These data show the currents were generally parallel to the right bank from the upstream end of the model to the lock and were an improvement over the original design. The velocity of the currents that would affect tows navigating the reach upstream of the dam varied from about 3.2 to 5.6 fps near the upstream end of the model, 2.8 to 5.2 fps about 2,500 ft upstream of the dam, and 2.1 to 3.6 fps near the upstream end of the guard wall with the 51,800- and 107,500-cfs riverflows, respectively.

**Navigation conditions.** Navigation conditions were improved with all riverflows evaluated compared to the original design. With the 51,800-cfs riverflow a downbound tow could enter the bend at the upstream end of the model and drive close along the right bank from the upstream end of the model to the lock. However, as the riverflow increased there was a tendency for the tow to be moved toward the center of the channel and out of alignment with the



lock approach as it turned the curve. The tow could continue to drive toward the right bank and align with the guard wall about one tow length upstream of the wall. However, the tow was driving too fast and could not slow down to approach the wall at a safe speed. Upbound tows could move away from the guard wall and navigate upstream without any major difficulties with all riverflows evaluated.

## Experiments with Modified Plan A

### Description

Modified Plan A (Figure 7) was the same as Plan A except five submerged groins spaced about 350 ft apart with top el 766.0 were added along the right bank starting at about Sta 19+00 or 1,000 ft upstream of the guard wall. The location, azimuth, and top elevation of the dikes are shown in the table in Figure 7.

### Results

**Water-surface elevations.** Water-surface elevations obtained with modified Plan A are shown in Table 4. These data show minor differences in water-surface elevations compared to Plan A.

**Current directions and velocities.** Current directions and velocities obtained with modified Plan A are shown in Plate 6. Photo 12 shows the current upstream of the dam with the 107,500-cfs riverflow. These data show that the currents were aligned generally the same as with Plan A. However, the dikes reduced the velocity of the currents along the right bank slightly. The velocity of the currents that would affect tows navigating the reach upstream of the dam varied from about 3.2 to 4.9 fps near the upstream end of the model, 2.2 to 5.0 fps about 2,500 ft upstream of the dam, and 1.5 to 2.7 fps near the upstream end of the guard wall with the 51,800- and 107,500-cfs riverflows, respectively.

**Navigation conditions.** The submerged dikes along the right bank improved navigation conditions for downbound tows with all riverflows evaluated. With the 51,800-cfs riverflow, downbound tows could drive along the right bank from the upstream end of the model to the lock. The tow could align with the guard wall and start reducing speed two to three tow lengths upstream of the guard wall and approach the guard wall at a safe speed. However, as the riverflow increased to 107,500 cfs, a downbound tow driving the reach was still maneuvering to align with the guard wall one tow length from the upstream end of the wall (Photo 13). Any error in alignment could result in the tow either missing the approach or striking the upstream end of the guard wall. Upbound tows could move away from the guard wall and move upstream over the dike field without any major difficulties (Photo 14).



**Conclusions and recommendation.** Satisfactory navigation conditions cannot be developed for all riverflows with the lock located at the proposed position. The lock is too close to the bend for a downbound tow to make the turn and align with the lock approach without some type of flanking maneuver. Therefore, it is recommended that the lock be moved downstream as far as practical to allow more distance between the lock and the bend upstream of the lock.

## Experiments with Plan B

Preliminary experiments were conducted with the lock moved about 1,000 ft downstream to evaluate various excavation schemes for the upper and lower approaches to the lock. Several schemes of submerged dikes were also evaluated to determine the optimum arrangement for tows entering and leaving the upper lock approach. Plan B represents the best configuration of those schemes.

### Description

Plan B (Figure 8) utilized the same structures as the original design, but the structures were moved downstream about 1,000 ft to allow more distance between the lock and the bend upstream of the lock. The principal features simulated or reproduced in the model included the following:

- a. A navigation lock with clear chamber dimensions of 84 ft (width) and 720 ft (length) constructed on the right descending bank. The intersection of the center line of the lock and the upstream pintle of the lock was located at SPC 186,190 N; 1,390,220 E. This placed the lock and dam about 1,000 ft downstream of its proposed location with the original design. The tops of the lock walls were at el 792.5.
- b. A 735.73-ft-long ported guard wall with seventeen 25.46-ft-diam cells spaced 40 ft on centers with top el 778.0. The nose cell at the upstream end of the guard wall was a 26.46-ft-diam cell and a half cell joined the guard wall with the lock wall. The cells were capped with a solid concrete member that extended from the upstream end of the wall to the lock wall. The top of the concrete cap was at the same elevation as the top of the lock (el 792.5) and the bottom of the cap was at el 778.0. This provides eighteen 14.54-ft-wide port openings with top of ports at el 778.0. The concrete cap extended 1.0 ft landward of the cells to align with the lock chamber and provide a rubbing surface for tows that extended beyond the cells.
- c. A 725-ft-long solid lower guide wall extending downstream from the land-side lock wall with top el 792.5. The effective length of the guide wall measured from the downstream end of the riverside lock wall is 461.5 ft.

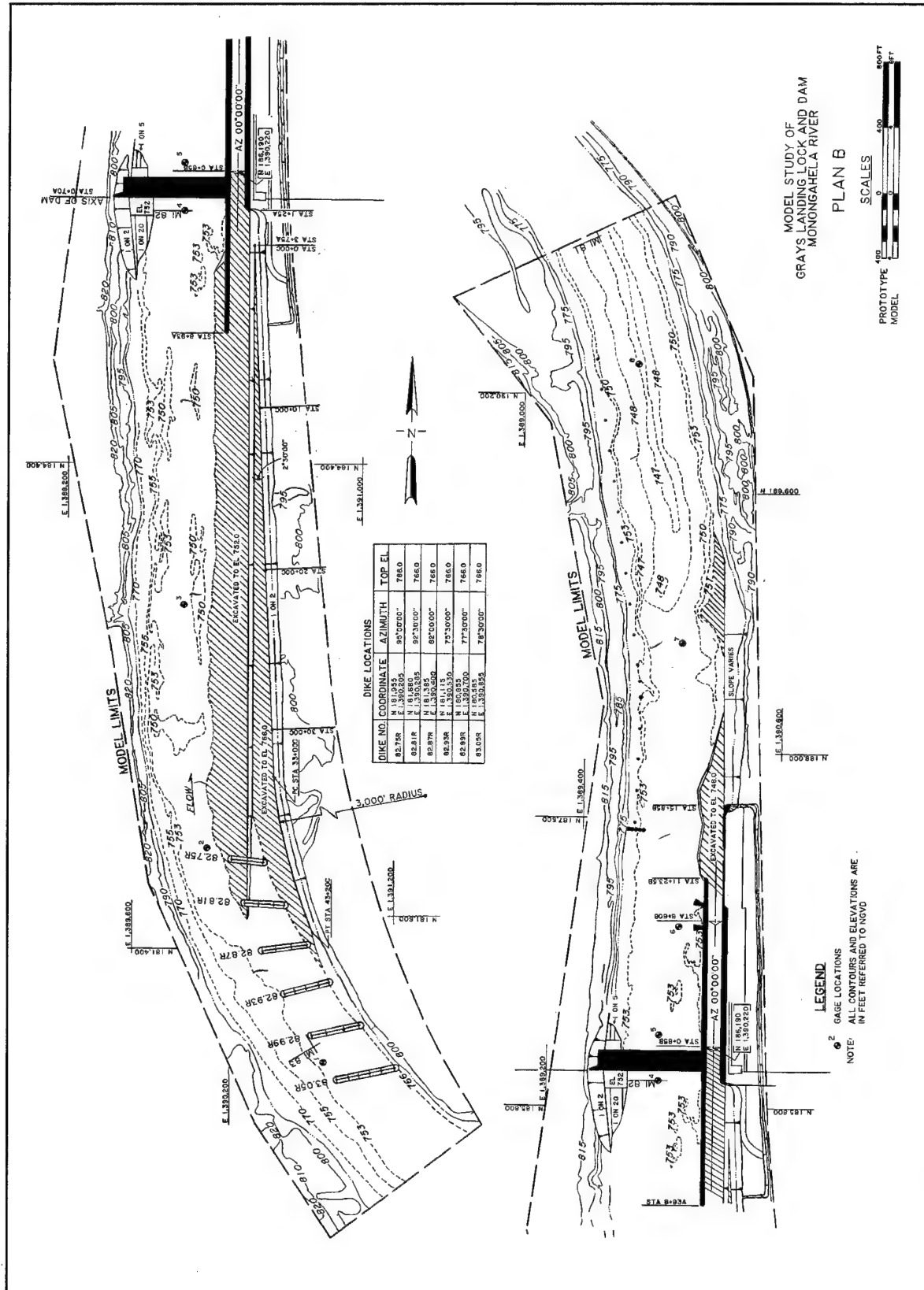


Figure 8. Plan B

- d. The navigation channel upstream of the lock was formed by two excavations (Figure 8). The right bank upstream of the lock was excavated to el 752.0 along a line extending from the outside face of the landside lock wall to a point about 4,100 ft upstream of the dam. The excavation tied into the natural contours of the riverbed, both riverward of the lock and at the upstream end of the excavation. A second excavation was made at el 766.0, which extended upstream from the outside face of the landside lock wall along a line angled to the left at  $2^{\circ} 30' 00''$  relative to the centerline to Sta 33+00. The excavation continued upstream from Sta 33+00 along a curve to the left with a radius of 3,000 ft. The excavation tied into the natural contours at its upstream end and the other excavation on the riverside. The bank slope of the excavation was 1V on 2H.
- e. The lower approach of the lock was excavated to el 748.0 and the right bank was realigned to provide a straight bank from the downstream end of the landside guide wall to a point about 1,500 ft downstream of the guide wall or about 3,100 ft downstream of the dam. The bank slope of the excavation varied to tie into the natural contours.
- f. A 576.08-ft-long fixed crest overflow weir extended across the river channel from the lock to the left bank. The crest of the weir was at el 778.0. The weir was connected to the left bank with a 15-ft-wide abutment and a 45-ft-long by 10-ft-wide non-overflow weir with top el 795.

## Results

**Water-surface elevations.** Water-surface elevations obtained with Plan B are shown in Table 5. These data show the slope in water surface elevations varied from about 0.2 to 0.5 ft per mile upstream of the dam with the 51,800- and 197,000-cfs riverflows, respectively. The slope in water surface downstream of the dam varied from about 0.8 to 1.2 ft per mile with the 51,800- and 168,000-cfs riverflows, respectively. The drop across the dam varied from about 11.7 to 3.0 ft with the 51,800- and 197,000-cfs riverflows, respectively.

**Current directions and velocities.** Current directions and velocities obtained with Plan B are shown in Plates 7-9. Photos 15-18 show the current pattern with the 51,800-cfs and 107,500-cfs riverflows. These data show the currents are generally parallel to the right bank from the upstream end of the model to the lock with the higher velocities being toward the center of the channel. The velocity of the currents that would affect tows navigating the reach upstream of the dam varied from about 3.1 to 5.5 fps near the upstream end of the model, 1.7 to 2.5 fps about 3,500 ft upstream of the dam, and 2.3 to 3.8 fps near the upstream end of the guard wall with the 51,800- and 107,500-cfs riverflows, respectively. A clockwise eddy formed in the forebay of the lock along the right bank with the higher riverflows (Photos 15 and 17). The velocity of the upstream current in the eddy was less than 0.5 fps.



The flow moves across the fixed-crest weir, follows the riverside of the lock to its downstream end, and then moves across the lower approach of the lock toward the downstream end of the guide wall. The row of cells (icebreakers) extending riverward from the left bank opposite the midpoint of the guide wall tended to direct the flow toward the guide wall (Photos 16 and 18). The velocity of the currents downstream of the dam ranged from about 5.9 to 11.4 fps between the guide wall and the icebreaker cells, 5.1 to 7.3 fps about 3,000 ft downstream of the dam, and 4.5 to 6.5 fps near the downstream end of the model with the 51,800- and 107,500-cfs riverflows, respectively.

**Navigation conditions.** Navigation conditions were satisfactory for all riverflows up to the maximum navigable riverflow of 107,500 cfs. A downbound tow could enter the modeled reach near midchannel, drive over the submerged dikes along the right bank, make the turn toward the lock approach, align with the guard wall 2 - 3 tow lengths upstream of the wall, start reducing speed, and approach the guard wall at a safe speed (Photo 19). Upbound tows could move away from the guard wall and navigate upstream along the right bank without any difficulties with all riverflows evaluated (Photo 20). Downbound tows experienced some difficulties moving away from the guide wall due to the current moving across the lower lock approach. The tow was required to rotate the head of the tow away from the guide wall before leaving the immediate approach (Photo 21). There was a tendency for a tow pushing straight downstream off the end of the guide wall to be pushed into the right bank downstream of the guide wall. Upbound tows could navigate the reach, land on the guide wall, and push into the lock chamber without any major difficulties (Photo 22). However, there was a tendency for the tow to be moved toward the right bank immediately downstream of the guide wall.

## Experiments with Modified Plan B

### Description

Modified Plan B (Figure 9) was the same as Plan B, except for the following:

- a. The slope of the right bank excavation upstream of the lock was changed from 1V on 2H to a 1V on 3H.
- b. A slightly different design for the lock was developed by the Pittsburgh District. The center line of the upper gate pintle was moved upstream 85.0 ft and the river wall of the lock extended upstream to Sta 1+57.27A. This moved the end of the guard wall 3 ft downstream to Sta 8+90A. The overall length and design of the wall were the same as Plan B.
- c. The original icebreaker cells along the left bank opposite the guide wall were replaced with a smaller structure that allowed flow to pass between the cells and the left bank.

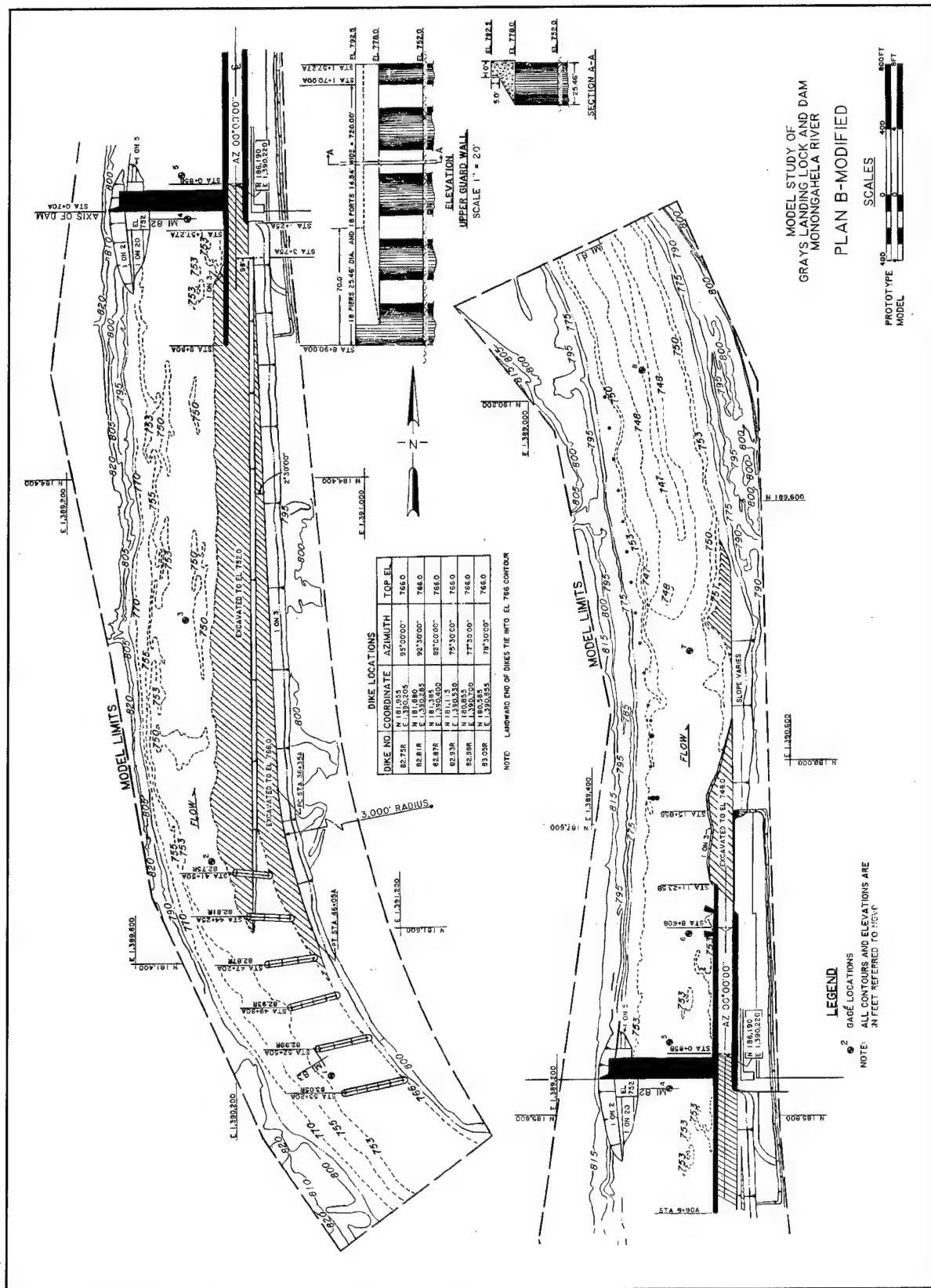


Figure 9. Modified Plan B

## Results

With modified Plan B experiments were conducted downstream of the dam with and without the new icebreaker cells in place to determine both the back-water effect of the cells and their influence on navigation conditions for tows entering and leaving the lower lock approach.

**Water-surface elevations.** Water-surface elevations obtained with modified Plan B and the new icebreaker cells in place are shown in Table 6. These data show the slope in water-surface elevations through the modeled reach were generally the same as with Plan B. Water-surface elevations obtained with modified Plan B without icebreaker cells in place are shown in Table 7. These data indicate that removing the cells had very little effect on the slope in water-surface elevations through the reach.

**Current directions and velocities.** Current directions and velocities obtained with modified Plan B with the new icebreaker cells in place are shown in Plates 10 - 12. Photos 23 and 24 show the current pattern in the upper lock approach with the 51,800- and 107,500-cfs riverflows. Plate 13 shows current directions and velocities measured without the new icebreaker cells and Photos 25 and 26 show the current pattern downstream of the dam without the new icebreaker cells. These data indicate the currents upstream of the dam were generally the same as with Plan B except along the right bank where the velocities were somewhat lower. The currents are generally parallel to the right bank from the upstream end of the model to the lock, with the higher velocities being toward the center of the channel. Along the right bank immediately downstream of the bend, the velocity of the current was less than 0.5 fps in some cases. The velocity of the currents that would affect tows navigating the reach upstream of the dam varied from about 3.2 to 5.9 fps near the upstream end of the model, 2.1 to 2.8 fps about 3,500 ft upstream of the dam, and 2.4 to 4.0 fps near the upstream end of the guard wall with the 51,800- and 107,500-cfs riverflows, respectively. A clockwise eddy formed in the forebay of the lock along the right bank with the higher riverflows (Photo 24). The velocity of the upstream current in the eddy was less than 1.0 fps.

With the new icebreaker cells in place opposite the downstream end of the guide wall, the flow moved across the fixed-crest dam, followed the riverside of the lock, moved across the lower approach to the lock at a slight angle, and reattached to the right bank 400 to 600 ft downstream of the guide wall. The maximum velocity of the currents that would affect tows entering and leaving the lock varied from about 5.9 to 8.0 fps near the downstream end of the guide wall, 5.3 to 7.5 fps about 3,000 ft downstream of the dam, and 4.5 to 7.7 fps near the downstream end of the model with the 51,800- and 107,500-cfs riverflows, respectively (Plates 10 - 12).

Without the new icebreaker cells, the flow moved across the lower approach to the lock with less angle than when the cells were in place (Plate 13). The maximum velocity of the currents that would affect tows entering and leaving the lock varied from about 5.6 to 7.2 fps near the downstream end of the guide

wall, 5.2 to 7.5 fps about 3,000 ft downstream of the dam, and 4.7 to 6.6 fps near the downstream end of the model with the 51,800- and 107,500-cfs riverflows, respectively.

**Navigation conditions.** Navigation conditions upstream of the dam were generally the same as with Plan B. Navigation conditions were satisfactory for all riverflows up to the maximum navigable riverflow of 107,500 cfs. A downbound tow could enter the modeled reach near midchannel, drive over the submerged dikes along the right bank, make the turn toward the lock approach, align with the guard wall 2 - 3 tow lengths upstream of the wall, start reducing speed, and approach the guard wall at a safe speed (Photos 27 - 29). Upbound tows could move away from the guard wall and navigate upstream along the right bank without any difficulties with all riverflows evaluated (Photos 30 - 32).

Navigation conditions downstream of the dam were satisfactory for all riverflows evaluated with the new icebreaker cells in place. However, some maneuvering was required for a downbound tow to move away from the guide wall and navigate through the reach.

Navigation conditions downstream of the dam were satisfactory for all riverflows evaluated without the new icebreaker cells. Downbound tows could move away from the guide wall and navigate through the reach with a minimum of maneuvering (Photos 33 - 35). Upbound tows could navigate the reach, land on the guide wall, and push into the lock chamber without any difficulties (Photos 36 - 38).

## **Cofferdam Experiments**

### **Discussion and purpose of experiments**

Modified Plan B was selected as the preferred plan and additional experiments were conducted to evaluate various phases of construction.

The Gray's Landing structures will be constructed in three phases. The lock with its guard and guide walls will be constructed during the first phase. The left bank abutment and a part of the fixed crest weir will be constructed during the second phase and the remaining part of the fixed crest weir will be constructed during the third and last phase of construction. During the first phase of construction, the size of the cofferdam and the width of the navigation channel through the reach were determined by the need to construct the lock inside a single cofferdam. During this phase of construction, tows will have about 400 to 500 ft of navigation channel between the cofferdam and the left bank except in the vicinity of the icebreaker cells, where the channel will be constricted to about 300 ft.

The fixed-crest dam will be constructed using two cofferdams. In the second phase of construction, the left bank abutment and some length of fixed-crest weir will be constructed inside a cofferdam connected to the left bank. Tows

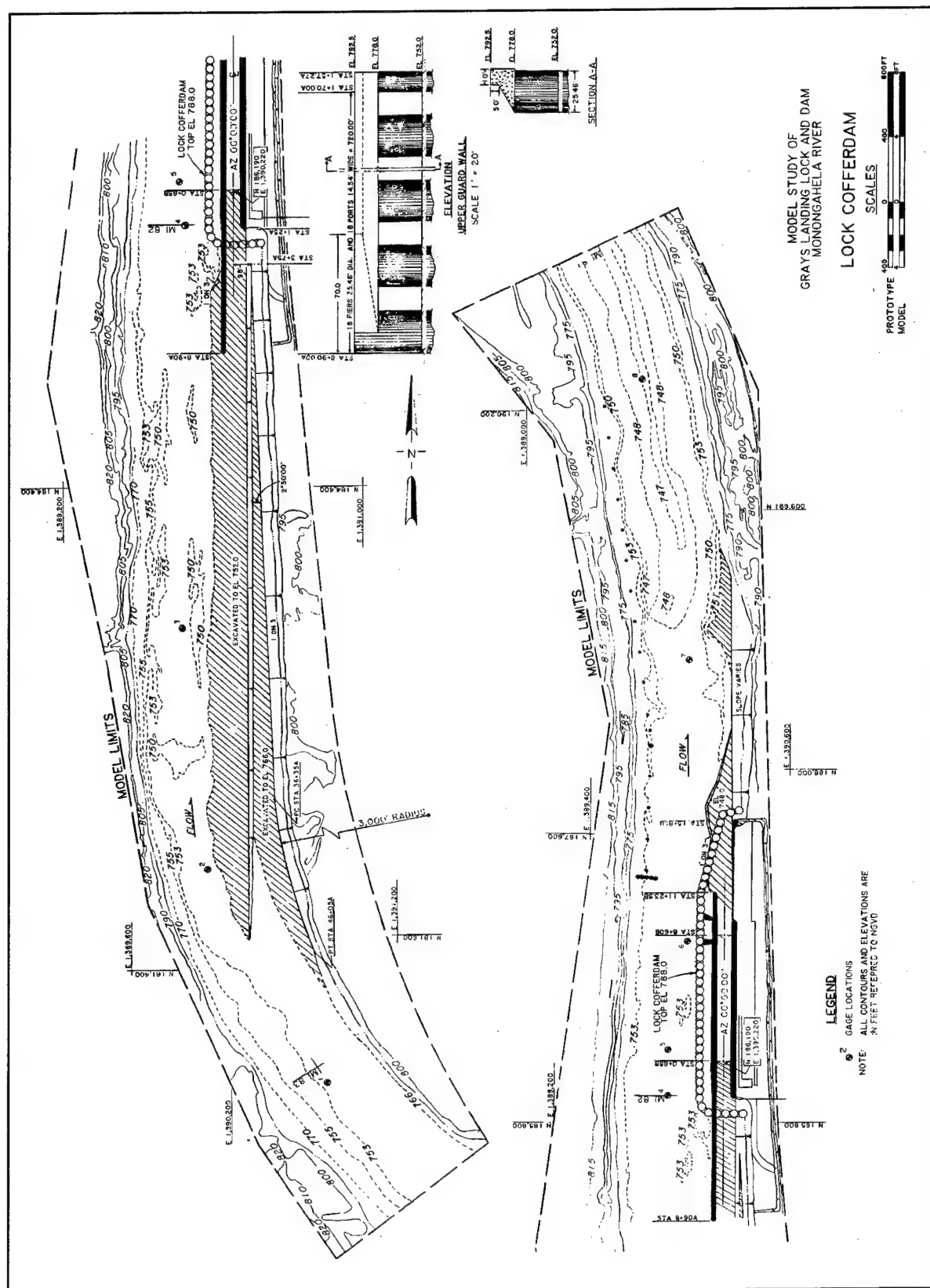
navigating the reach will be able to use the channel between the cofferdam and the new lock to avoid locking through the reach. During low flow conditions, when the water depth in the upper lock approach is not deep enough for tows to use the lock, tows will use the navigation channel between the lock and the cofferdam. Experiments were conducted to evaluate navigation conditions with various widths of navigation channels and develop modifications required to establish satisfactory conditions for tows using the channel during low flow conditions. The goal was to minimize the width of navigation channel and maximize the size of cofferdam for construction of the first part of the dam.

In the third phase of construction, the remaining part of the fixed-crest dam will be constructed inside a cofferdam connected to the new lock. During this period of construction all flow will be passed over the completed part of the dam and a higher-than-normal pool will exist upstream of the dam. There was concern that the higher stages upstream of the dam could exceed the flow easement right obtained by the Corps of Engineers. Therefore, an effort was made to maximize the length of dam constructed during the second phase of construction. Tows will be locking through the project.

### **Description of lock cofferdam**

The lock, lower guide wall, and a part of the upper guard wall will be constructed inside a cofferdam with top el 788.0. The cofferdam will be tied into the right bank both upstream and downstream of the lock (Figure 10 and Photo 39). The principal features simulated in the model were as follows:

- a. A cofferdam was constructed along the right bank for construction of the lock, emptying system, and lower guide wall. The top of the cofferdam was at el 788.0.
- b. About 600 ft of the ported guard wall was in place upstream of the cofferdam. The guard wall was the same design as Plan B and modified Plan B.
- c. The right bank upstream of the cofferdam was excavated to el 752.0 along a line extending from the outside face of the landside lock wall to a point about 4,100 ft upstream of the dam. The excavation tied into the natural contours of the riverbed both riverward of the lock and at the upstream end of the excavation. A second excavation was made at el 766.0, which extended upstream from the outside face of the landside lock wall along a line angled to the left at  $2^{\circ} 30' 00''$  relative to the centerline to Sta 33+00. The excavation continued upstream from Sta 33+00 along a curve to the left with a radius of 3,000 ft. The excavation tied into the natural contours at its upstream end and the other excavation on the riverside. The bank slope of the excavation was 1V on 3H. The excavation was the same as modified Plan B.



- d. The right bank downstream of the cofferdam was excavated to el 748.0 and realigned to provide a straight bank from the downstream end of the landside guide wall to a point about 1,500 ft downstream of the guide wall or about 3,100 ft downstream of the dam. The bank slope of the excavation varied to tie into the natural contours. The excavation was the same as Plan B and modified Plan B.

## Results

**Water-surface elevations.** Water-surface elevations obtained with the lock cofferdam and the existing icebreaker cells in place are shown in Table 9. These data show a significant increase in water-surface elevation upstream of the cofferdam (Gauge 3) when compared to existing conditions. The increase in water-surface elevations varied from about 12.5 ft to 1.5 ft with the 51,800- and 197,000-cfs riverflows, respectively. The slope in water surface elevations varied from about 0.2 to 0.7 ft per mile upstream of the dam with the 25,000- and 197,000-cfs riverflows, respectively. The slope in water-surface downstream of the dam varied from about 0.6 to 2.0 ft per mile with the 25,000- and 107,5000-cfs riverflows, respectively. The change in water-surface elevations from the upstream end of the cofferdam to the downstream end (Gauges 4 to 7) varied from about 0.5 to 2.1 ft with the 25,000- and 197,000-cfs riverflows, respectively.

Water-surface elevations obtained with existing icebreaker cells removed are shown in Table 10. These data show a decrease in water-surface elevations upstream of the existing icebreaker cells' location. The decrease in water-surface elevations at Gauge 5 varied from about 0.2 ft to 1.2 ft with the 25,000- and 107,500-cfs riverflows, respectively. The slope in water surface elevations varied from about 0.5 to 1.2 ft per mile upstream of the dam with the 25,000- and 157,000-cfs riverflows, respectively. The slope in water-surface downstream of the dam varied from about 0.4 to 0.6 ft per mile with the 25,000- and 157,000-cfs riverflows, respectively. The change in water-surface elevations from the upstream end of the cofferdam to the downstream end (Gauges 4 to 7) varied from about 0.3 to 0.9 ft with the 25,000- and 197,000-cfs riverflows, respectively. This shows a significant decrease in the slope in water-surface elevations compared to those taken with the existing icebreaker cells in place.

**Current directions and velocities.** Current directions and velocities obtained with the lock cofferdam and the existing icebreaker cells in place are shown in Plates 14 - 16. These data show that with the lower riverflows, the current follows the natural river channel from the upstream end of the model to the guard wall and cofferdam (Plates 14 and 15). The flow then moves through the opening between the cofferdam and the right bank parallel with the cofferdam from its upstream end to its downstream end. The flow then moves toward the right bank. With the lower riverflow, a large clockwise eddy forms along the right bank downstream of the cofferdam. As the riverflow increases, the size of the eddy decreases. The icebreaker cells along the left bank direct the flow away from the left bank and large eddies form along the left bank downstream of the



cells. As the riverflow increases, the size of the eddy increases. With the 107,500-cfs riverflow, the eddy downstream of the cells was very erratic (Photo 39).

The maximum velocity of the currents that would affect navigation through the reach with the icebreaker cells in place varied from 4.0 to 6.1 fps near the upstream end of the model, 3.7 to 7.7 fps near the upstream end of the guard wall, 5.6 to 14.1 fps in the channel between the icebreaker cells and the cofferdam, and 3.0 to 7.8 fps near the downstream end of the model with the 25,000- and 107,500-cfs riverflows, respectively.

Current directions and velocities taken with the icebreaker cells removed are shown in Plates 17 -19. Photo 40 shows the surface current patterns with the 107,500-cfs riverflow. These data show the alignment of the current upstream of the cofferdam was generally the same as with the existing icebreaker cells in place. However, with the existing icebreaker cells removed, the current was generally parallel with the left bank from the upstream end of the cofferdam to the downstream end of the model. The maximum velocity of the currents that would affect navigation through the reach without the icebreaker cells varied from 3.7 to 6.7 fps near the upstream end of the model, 3.9 to 7.6 fps near the upstream end of the guard wall, 4.9 to 10.5 fps in the channel between the cofferdam and the left bank, and 3.0 to 7.1 fps near the downstream end of the model with the 25,000- and 107,500-cfs riverflows, respectively.

**Spot velocities.** Spot velocity measurements were taken with a range of riverflows to evaluate the potential for scouring of the channel bed along the face of the cofferdam. The measurements were made with and without the existing icebreaker cells in place (Plates 20 and 21). The measurements were taken 10 ft away from the face of the cofferdam and 5 ft above the bottom of the river channel.

With the existing icebreaker cells in place the velocity of the currents near the upstream end of the cofferdam varied from about 3.9 to 7.2 fps with the 25,000- and 197,000-cfs riverflows, respectively (Plate 20). At Sta 11+23.5B, the maximum velocity of the currents varied from about 5.1 to 10.6 fps with the 25,000- and 107,500-cfs riverflows, respectively. With riverflows above 107,500 cfs, when the tailwater elevation exceeded 792.0 and the cofferdam became submerged, the velocity of the currents in the vicinity decreased somewhat.

Without the existing icebreaker cells the velocity of the currents near Sta 11+23.5B decreased considerably. The maximum velocity of the currents varied from about 3.9 to 7.2 fps with the 25,000- and 107,500-cfs riverflows, respectively (Plate 21). With riverflows above 107,500 cfs, when the tailwater elevation exceeded 792.0 and the cofferdam became submerged, the velocity of the currents in the vicinity decreased somewhat.

**Navigation conditions.** Navigation conditions with the existing icebreaker cells in place were unsatisfactory. Downbound tows could align with and enter the navigation channel between the upstream end of the cofferdam and the left



bank without any major difficulties. However, the currents in the vicinity of the icebreaker cells moved the tow toward the cofferdam and the tow had difficulty recovering without being moved into the right bank. With the lower riverflows, upbound tows could navigate up to the cofferdam without any major difficulties. As the tow approached the downstream end of the cofferdam, the erratic currents in the vicinity created extremely difficult navigation conditions. Considerable maneuvering was required for the tow to navigate the channel around the cofferdam. As the riverflow increased above 25,000 cfs and the velocity of the currents increased, navigation conditions became hazardous for tows in the vicinity of the cofferdam.

Navigation conditions without the icebreaker cells were satisfactory with all riverflows evaluated. Downbound tows could align with and enter the navigation channel between the cofferdam and the left bank and navigate past the cofferdam with a minimum of maneuvering (Photos 41 and 42). As the tow moved past the downstream end of the cofferdam, it could turn toward the left bank to counteract the currents moving toward the right bank. Upbound tows could enter the channel between the cofferdam and the left bank with a minimum of maneuvering. As the tow moved past the upstream end of the cofferdam, it was required to take a set toward the right bank to counteract the currents moving from the right bank toward the channel adjacent to the cofferdam (Photos 43 and 44).

Additional experiments were conducted with the proposed new icebreaker cells in place along the left descending bank. These experiments indicate the new icebreaker cells would increase the maneuvering required for tows navigating the reach. Downbound tows could navigate the reach without any major difficulties (Photos 45 and 46). However, upbound tows would experience erratic currents in the vicinity of the new icebreaker cells at a critical point in their approach to the channel adjacent to the cofferdam (Photos 47 and 48). The track of the lights on the pusher show considerable maneuvering would be required for the tow to maintain alignment and navigate past the new icebreaker cells, especially with the 107,500-cfs riverflow.

### **Experiments with the first stage of the dam cofferdam**

Experiments were conducted with three sizes for the first stage of the dam cofferdam. The various sizes of cofferdam would provide a navigation channel between the completed lock and the cofferdam of varying widths depending on the cofferdam. The three channels were 125 ft wide, 175 ft wide, and 225 ft wide.

**General description.** The principal features reproduced or simulated in the model were generally the same as with the lock cofferdam, except for the following:

- a. The lock cofferdam was removed, leaving a lock with clear chamber dimensions of 84 ft (width) and 720 ft (length) with its upstream guard wall and downstream guide wall adjacent to the right descending bank.
- b. The first stage of the dam cofferdam was constructed along the left descending bank to facilitate construction of the fixed crest dam. The size of the cofferdam varied depending on the width of navigation pass being evaluated.

**First stage dam cofferdam with 125-ft-wide navigation pass.** The cofferdam was sized to provide a 125-ft-wide navigation pass between the lock and the cofferdam. Experiments were conducted to evaluate navigation conditions for a 70-ft-wide by 685-ft-wide tow and a 35-ft-wide by 685-ft-wide tow navigating through the channel between the lock and cofferdam. Navigation conditions were evaluated with 6,000-, 12,000-, and 25,000-cfs riverflows.

Dye and confetti indicated the concentrated flow through the navigation pass and the expansion immediately downstream of the cofferdam would create a large clockwise eddy in the lower approach of the lock with the 25,000-cfs riverflow. With the 6,000- and 12,000-cfs riverflows, the eddy was somewhat smaller. The maximum velocity of the currents in the navigation pass varied from about 5.5 to 15 fps with the 6,000- and 25,000-cfs riverflows, respectively. The velocity of the currents increased significantly as the tow entered the pass due to the percentage of area occupied by the tow compared to the total cross section of the pass (37 percent and 19 percent with the 70-ft-wide and 35-ft-wide tows, respectively).

Navigation conditions were hazardous for 70-ft-wide by 685-ft-long tows using the navigation pass with all riverflows evaluated. Downbound tows could align with and enter the navigation pass but as the tow entered the pass and the velocity of the currents increased, the tow could not maintain control and could be moved into the cofferdam or the lock. Downbound 35-ft-wide by 685-ft-long tows could navigate through the pass with the 6,000-cfs riverflow provided the tow approached and entered the pass near its center line. Upbound tows approached the navigation pass with a 20- to 25-deg set toward the lock to compensate for the currents moving toward the left bank. As the tow entered the pass and the velocity of the currents increased, the tow would tend to stall in the pass. Considerable maneuvering was required to maintain control and there was a possibility of striking either the cofferdam or the lock.

**First stage dam cofferdam with 175-ft-wide navigation pass.** The configuration of the model was the same as with the 125-ft-wide navigation pass except the cofferdam was modified to provide a 175-ft-wide navigation pass between the lock and the cofferdam (Figure 11).

Current directions and velocities taken with the 175-ft-wide pass are shown in Plates 22 - 25. These data show the currents generally follow the left bank from the upstream end of the model to a point about 2,000 ft upstream of the axis of the dam and then move toward the navigation pass between the lock and



cofferdam. The current tends to sweep around the upstream end of the cofferdam to move into the pass. Some flow also moves through the guard wall ports to enter the navigation pass. As the flow exits the pass at the downstream end of the cofferdam, the flow expands toward the left bank and then a short distance downstream moves toward the right bank. A large counterclockwise eddy forms along the left bank immediately downstream of the cofferdam. The maximum upstream velocity of the currents varied from less than 0.5 fps to about 4.0 fps with the 6,000- and 51,800-cfs riverflows. A large clockwise eddy forms along the right bank immediately downstream of the lock. The upstream velocity of the currents varied from less than 0.5 fps to about 2.5 fps with the 6,000- and 51,800-cfs riverflows, respectively. The maximum velocity of the currents that would affect navigation through the reach varied from 1.4 to 4.7 fps near the upstream end of the model, 1.1 to 5.0 fps near the upstream end of the guard wall, 2.7 to 15.4 fps in the channel between the cofferdam and the lock, and 0.9 to 4.8 fps near the downstream end of the model with the 6,000- and 51,800-cfs riverflows, respectively.

Navigation conditions were satisfactory both for upbound and downbound tows moving through the navigation pass with riverflows through 12,000 cfs. Some maneuvering was required for upbound tows to align with and enter the navigation pass. As the riverflow increased to 25,000 cfs, navigation conditions through the pass became unsatisfactory due to the restricted width of the pass and the high velocity of the currents. With the 25,000-cfs riverflow, downbound tows could align with the lock approach but considerable maneuvering could be required for the tow to align with and enter the lock chamber due to the limited width of the lock approach. As the tow approached the lock chamber, there was a strong pull toward the guard wall due to the concentrated flow moving through the most downstream guard wall ports. Upbound tows had some difficulties moving away from the guard wall and proceeding upstream. With the 51,000-cfs riverflow, the concentration of flow through the downstream ports of the guard wall that was present with the 25,000-cfs riverflow was reduced considerably and tows could enter and leave the upper lock approach without any major difficulties. Navigation conditions for tows entering and leaving the lower lock approach were unsatisfactory and could be hazardous. There was a tendency for the upstream eddy to rotate a downbound tow and move it into the right bank. Upbound tows experienced erratic high-velocity currents approaching the lock and there was a tendency for the tow to be moved into the guide wall with considerable force. As the tow moved up along the guide wall to enter the lock chamber, the head of the tow was moved riverward by the eddy and the tow was rotated in the lock approach. There was an indication the head of the tow could be moved riverward of the approach into the high-velocity currents passing through the navigation pass and be swept downstream into the left bank or the stern of the towboat being grounded on the right bank.

**First stage dam cofferdam with 225-ft-wide navigation pass.** The configuration of the model was the same as with the 125-ft-wide and 175-ft-wide navigation pass, except the cofferdam was modified to provide a 225-ft-wide navigation pass between the lock and the cofferdam (Figure 12).

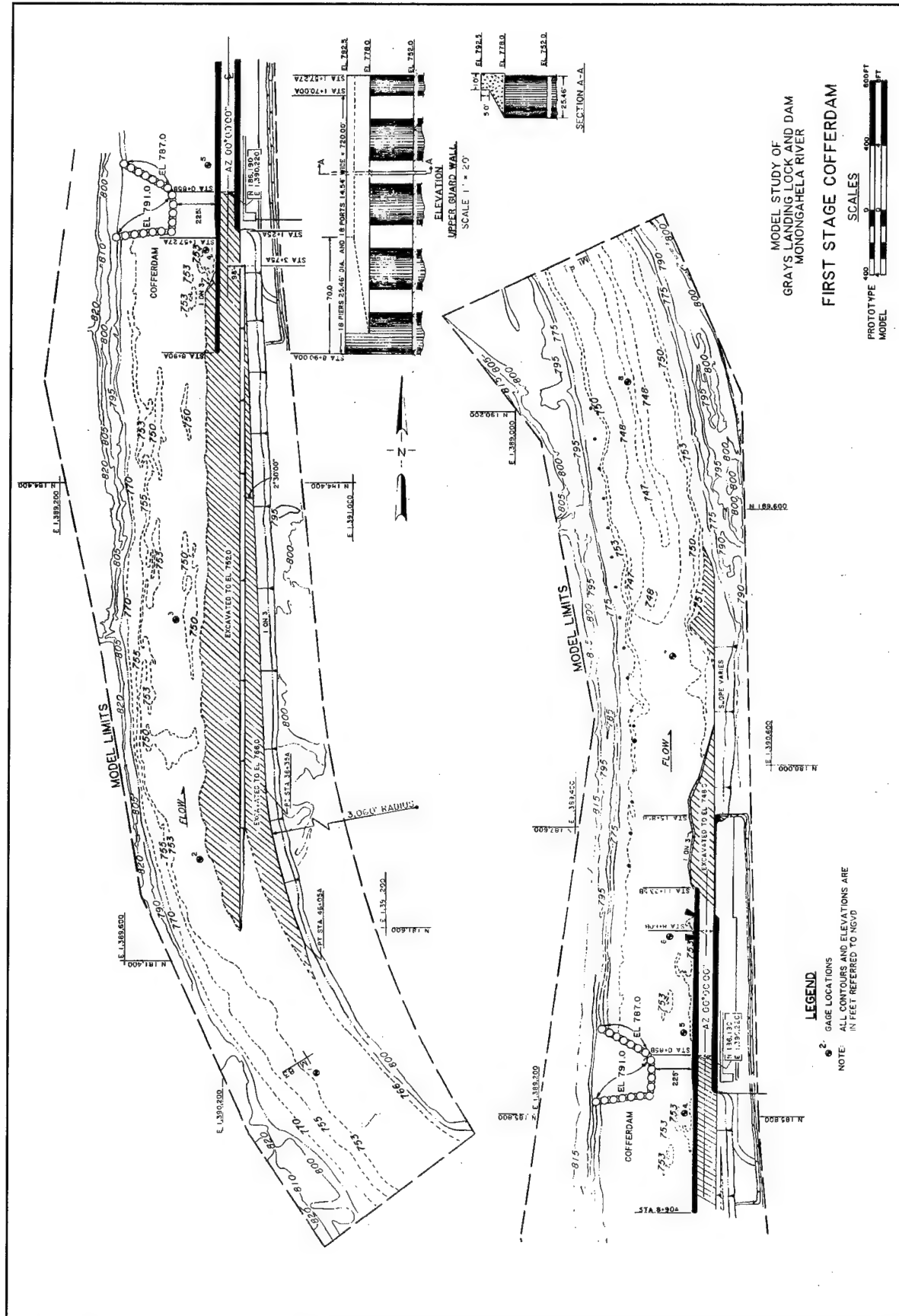


Figure 12. First stage of dam cofferdam, 225-ft-wide navigation pass

Current direction and velocities taken with the 225-ft-wide pass are shown in Plates 26 - 28. These data show that the alignment of the currents is generally the same as with the 175-ft-wide navigation pass. Large eddies still formed downstream of the cofferdam and downstream of the lock. The maximum velocity of the currents that would affect navigation through the reach varied from 1.4 to 4.7 fps near the upstream end of the model, 2.9 to 6.8 fps near the upstream end of the guard wall, 6.9 to 19.2 fps in the channel between the cofferdam and the lock, and 2.1 to 9.5 fps near the downstream end of the model with the 12,000- and 107,500-cfs riverflows, respectively.

Navigation conditions were satisfactory for tows moving through the navigation pass with riverflows through 25,000 cfs. Some maneuvering would be required for upbound tows to enter and move through the navigation pass. Considerable power would be required for upbound tows to push through the pass with the 25,000-cfs riverflow. As the riverflow increased to 51,800-cfs, navigation conditions for tows using the navigation pass became unsatisfactory due to the high velocity of the currents and the maneuvering required for the tow to move through the pass. Navigation conditions were satisfactory for tows entering and leaving the upper lock approach with all riverflows evaluated. However, with the higher riverflows as the tow approached the lock chamber, there was a strong pull toward the guard wall due to the concentrated flow moving through the most downstream guard wall ports. Navigation conditions were satisfactory for tows entering and leaving the lower lock approach with all riverflows evaluated. Downbound tows could move away from the guide wall and navigate downstream without any major difficulties. With the 25,000- and 51,800-cfs riverflows, some maneuvering was required for upbound tows to approach the lock and land on the guide wall. With the 51,800-cfs riverflows, there was a tendency for the head of the tow to be moved away from the guide wall as it approached the lock chamber.

#### **Conclusions and recommendations:**

- a. A 125-ft-wide navigation pass will not provide satisfactory navigation conditions through the pass even with the lowest riverflow.
- b. With the 175-ft-wide navigation pass, satisfactory navigation conditions can be established with riverflows of 12,000 cfs and less.
- c. With the 225-ft-wide navigation pass, satisfactory navigation conditions can be established with riverflows through 25,000 cfs.
- d. A system of spur dikes along the left bank downstream of the cofferdam could improve navigation conditions for tows navigating through the pass and tows entering and leaving the lower lock approach, especially with the 175-ft-wide pass.
- e. Closing some of the ports of the guard wall would improve navigation conditions for tows navigating through the pass and for tows entering and leaving the upper lock approach.

- f. Protection cells should be provided both upstream and downstream of the cofferdam to prevent a tow from striking the main cells of the cofferdam.

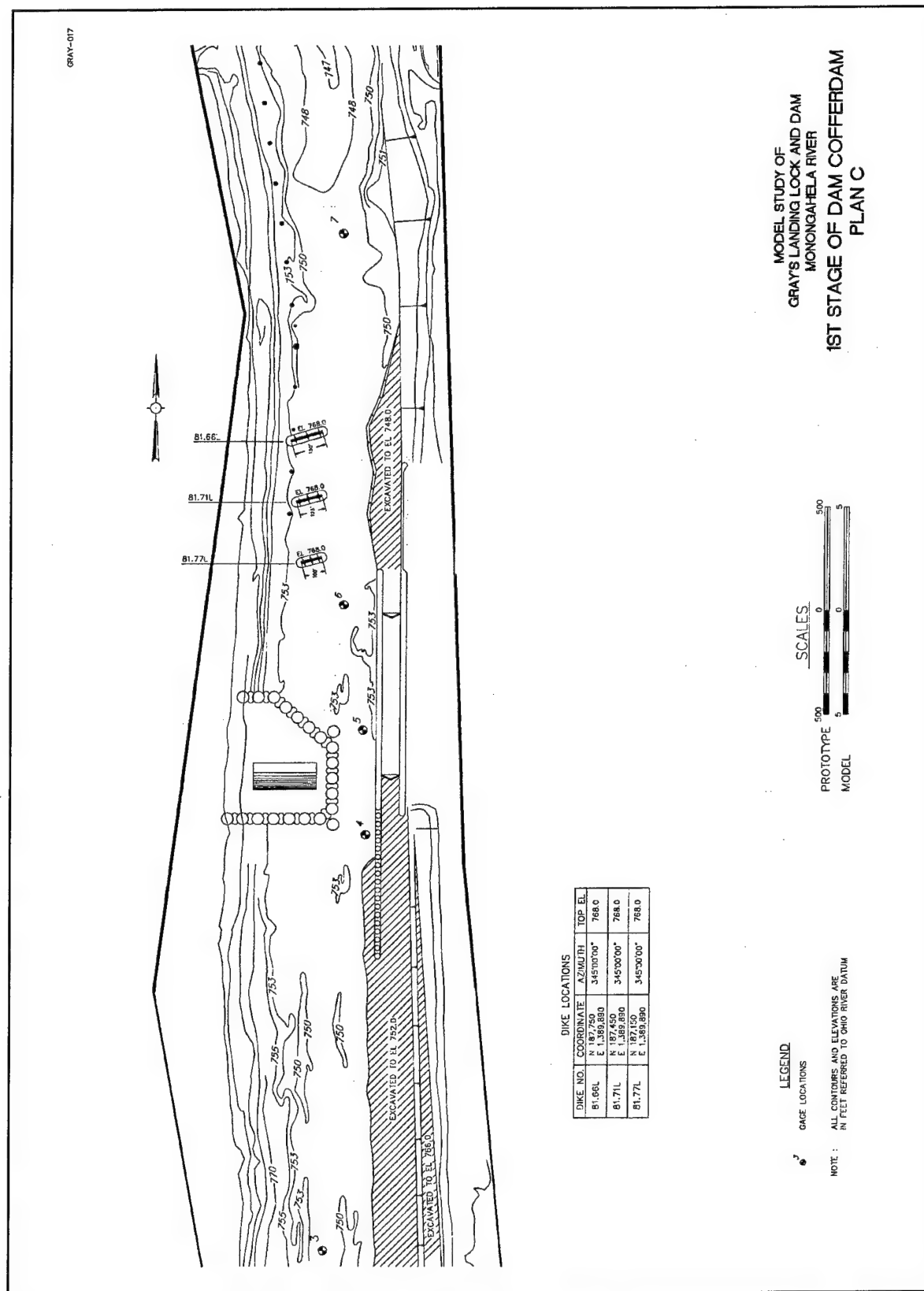
**175-ft-wide navigation pass modified (selected plan).** Based on the previous experiments and construction consideration, Pittsburgh District selected the 175-ft-wide navigation pass as the preferred plan for the first stage of the dam cofferdam. Preliminary experiments were conducted to develop modifications that would provide satisfactory navigation conditions with the widest range of riverflows. A series of experiments were conducted to develop a port closure scheme for the upper guard wall to eliminate the strong pull to the wall. Several designs of dikes and dike fields were evaluated to reduce or eliminate the large eddy along the right bank in the vicinity of the lower lock approach. These modifications were incorporated in this plan.

The configuration of the model (Figures 13 and 14 and Photo 49) was the same as the 175-ft-wide navigation pass previously evaluated, except:

- a. Three dikes with top elevations of 768.0 were placed along the left descending bank opposite the lower lock approach (Photo 49). The dikes were of varying lengths, with the most upstream dike being 100 ft long, the next dike being 125 ft long, and the most downstream dike being 150 ft long. The dikes were spaced 300 ft apart and angled downstream 15 deg. The riverward end of the dikes was 330 ft riverward of the center line of the lock. A table listing the coordinates and azimuth of the dikes is included in Figure 13.
- b. A slightly modified version of the first stage of the dam cofferdam was constructed along the left descending bank to facilitate construction of the fixed crest dam (Figure 14). The upstream leg of the cofferdam was parallel with the dam and the downstream leg angled downstream before running parallel with the dam and tying into the left bank. Two 60-ft-diam protection cells were placed upstream and downstream of the cofferdam. The riverward face of the cells was placed 5 ft riverward of the alignment of the cofferdam cells. This provided a 170-ft-wide navigation pass at the protection cells and a 175-ft width between the cofferdam and the lock. Therefore, the navigation pass has an effective width of 170 ft.
- c. To prevent adverse flow through the guard wall at the navigation pass, the ports in the first 200 ft of the guard wall adjacent to the lock were fully closed and ports in the next 100 ft were closed to el 768.0.

**Water-surface elevations.** Water-surface elevations recorded with the various riverflows and the first stage of the dam cofferdam in place are shown in Table 11. Gauge 4 is located near the center of the navigation pass at the upstream end of the cofferdam and is in the drawdown of the navigation pass. Therefore, the slope in water-surface elevations through the restricted reach is referenced to Gauges 3 and 6. Data presented in Table 11 indicate the slope in water-surface elevations through the constricted reach formed by the lock and





**Figure 13. First stage of dam cofferdam, 175-ft-wide navigation pass modified**



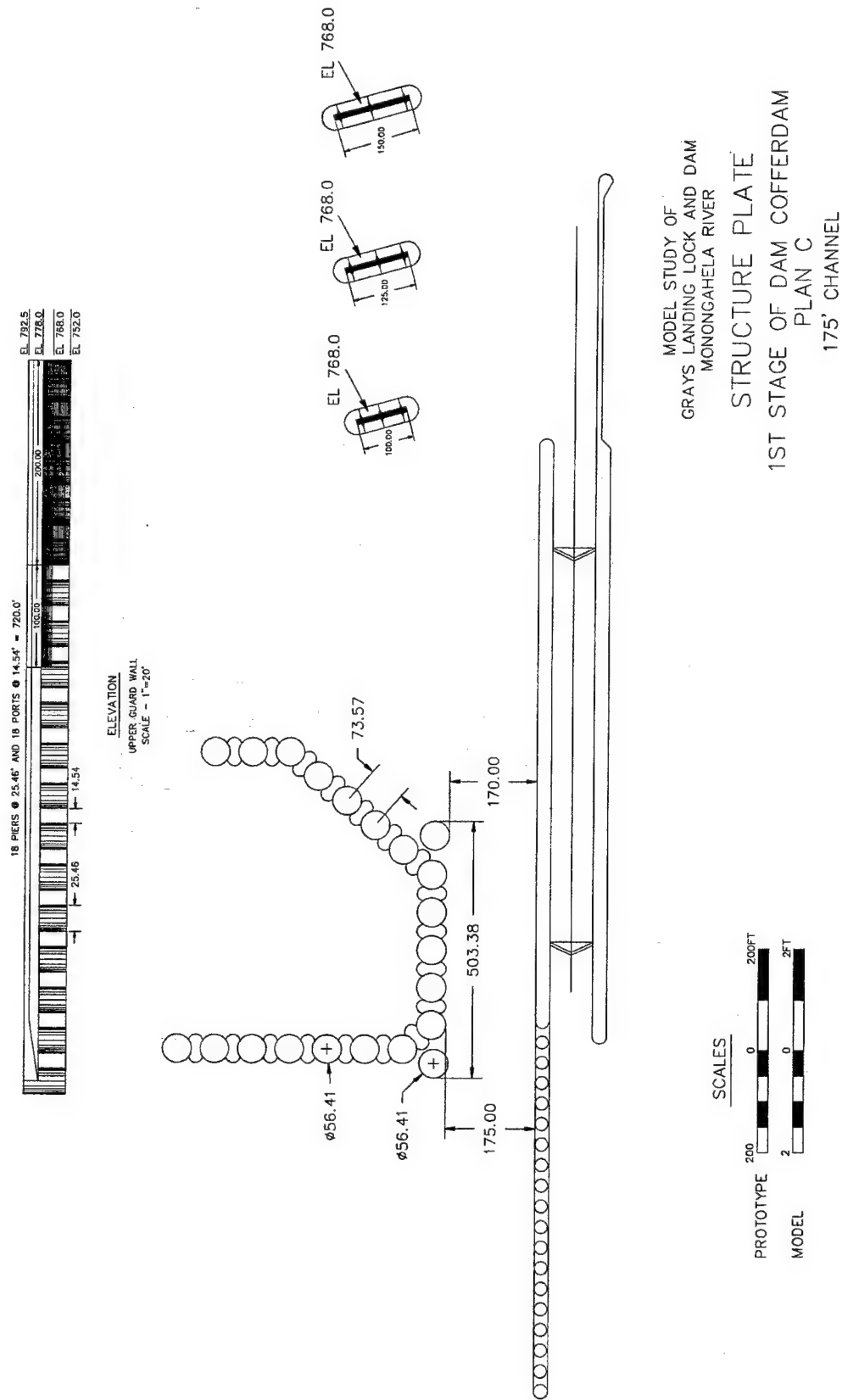


Figure 14. Structures, first stage of dam cofferdam

first stage cofferdam varied from 0.3 to 9.0 ft with the 6,000- and 107,500-cfs riverflows, respectively (Gauges 3-6).

**Current directions and velocities.** Current direction and velocity data taken with the first stage of the dam cofferdam in place are shown in Plates 29 - 34. These data indicate the currents are generally parallel with the right descending bank upstream of the lock and there was no appreciable outdraft near the upstream end of the guard wall. The flow entering the upper lock approach appeared to be evenly distributed along the upper end of the ported guard wall where the ports were fully open. The currents were generally parallel to the lock approaching and through the 170-ft effective width navigation pass with the velocities of the currents being almost uniform across the navigation pass, except near the cofferdam. As the flow exited the navigation pass, there was a tendency for the flow to expand toward the left bank. This expansion was controlled somewhat by the three dikes along the left bank opposite the lower lock approach. A large clockwise eddy formed in the lower lock approach and its size and intensity increased as the riverflow increased. The maximum velocity of the currents along the normal sailing line of a tow approaching the upper guard wall varied from about 1.5 fps with the 6,000-cfs riverflow to about 3.8 fps with the 51,800-cfs riverflow. The maximum velocities of the currents varied from about 2.5 to 11.5 fps approaching the navigation pass, about 4.8 to 22.6 fps in the pass, about 3.4 to 20.4 fps near the downstream end of the lock, and 2.9 to 17.2 fps opposite the most downstream left bank dike with the 6,000- and 107,500-cfs riverflows, respectively. The maximum velocity of the upstream currents in the clockwise eddy that forms in the lower lock approach varied from less than 0.5 fps to about 8.3 fps with the 6,000- and 107,500-cfs riverflows, respectively. The maximum upstream current velocities in the lower lock approach that tows would encounter would be about 2.3 fps, which occurred with the 51,800-cfs riverflow. The 107,500-cfs riverflow is not considered to be navigable.

**Point velocities.** Meter velocities taken in the navigation pass and near the riverward ends of the three left bank dikes are shown in Plates 35 and 36. Maximum current velocities of about 23.0 fps occurred in the navigation pass and 21.8 fps occurred adjacent to the upstream protection cell with the 107,500-cfs riverflow. These data indicated the riverward end of the most downstream dike would encounter the highest currents with a maximum velocity of 14.9 fps, which occurred with the 107,500-cfs riverflow.

**Navigation conditions.** Navigation conditions were evaluated for tows using the navigation pass with the 6,000-, 9,000- and 12,000-cfs riverflows and for tows entering and exiting the lock with the 12,000, 25,000, and 51,800-cfs riverflows. Navigation conditions were satisfactory for downbound and upbound tows using the navigation pass with a riverflow of 6,000 cfs. With the 6,000-cfs riverflow, downbound tows could align with and move through the navigation pass without any major difficulties (Photo 50 and Plates 37 and 38). There was no tendency for the tow to be pushed into the cofferdam, guard wall, or the lock wall as it moved through the pass. As the tow exited the pass in the downbound direction, the currents moved the tow toward the left bank dikes but the tow could steer away from the dikes and continue downstream. An upbound tow

approaching the navigation pass would take a set toward the lock to counteract the currents moving toward the left descending bank (Photo 51 and Plates 39 and 40). The tow would continue to hold its set toward the lock until about half of the tow was in the pass. At that point, the tow would be able to align with and move upstream through the pass. The tow would occupy a large portion of the pass width as it enters the navigation pass.

With the 9,000-cfs riverflow, navigation conditions for upbound and downbound tows were generally the same as with the 6,000 cfs, except the tow would encounter slightly higher current velocities in the navigation pass (Plates 41 and 42). The alignment of the currents approaching and exiting the pass appeared to be satisfactory for tows to navigate through the pass. There was a tendency for a downbound tow exiting the pass to be moved toward the left bank dikes by the currents but the tow should be able to steer away from the dikes (Plates 43 and 44). Upbound tows would encounter current velocities of about 5.5 fps in the pass. It should be noted that these current velocities would increase somewhat due to the cross-sectional area blocked by the tow as it moves into the pass. Provided tows have sufficient power to move upstream against these currents, tows should be able to bypass the lock with the 9,000-cfs riverflow.

With the 12,000-cfs riverflow, tows using the navigation pass would encounter high current velocities in the navigation pass and adverse current patterns immediately upstream and downstream of the cofferdam. Downbound tows bypassing the lock could align with and move through the pass; however, there was a tendency for the tow to be pushed into the lock as the tow entered the pass (Plates 45 and 46). The currents in the pass would accelerate the speed of the tow and as the tow left the pass there was a strong tendency for the currents to move the tow into the left bank dikes (Photo 52 and Plates 45 and 46). An upbound tow would approach the navigation pass in much the same manner as with the 6,000 cfs, but the set of the tow toward the lock increased slightly (Photo 53 and Plates 47 and 48). The tow would also encounter high-velocity currents in the navigation pass which would increase somewhat over those shown on Plate 31 due to the amount of the cross-sectional area blocked by the tow as it enters the pass. A very high-powered tow would be required to push the design size tow upstream through the pass. These conditions would be unsafe for tows navigating the pass due to the alignment of the currents through the reach, the high velocities of the currents in the pass, and the danger of a tow striking the left bank dikes.

With the 12,000-, 25,000-, and 51,800-cfs riverflow, tows could enter and leave the upper lock approach without any major difficulties (Photos 54 - 59). However, it should be noted that with the 12,000- and 25,000-cfs riverflows, the upper lock approach is restricted due to the 766.0 elevation excavation along the right descending bank approaching the lock. With the upper pool elevations being experienced during this phase of construction, the depth over the right bank excavation will not accommodate a tow drafting 9.0 ft with riverflows of 12,000 and 25,000 cfs. It should also be noted that the rubbing surface of the guard wall will be above the water-surface elevation with riverflows less than 51,800 cfs. This will expose the guard wall cells to impact from tows moving

along the wall. With the 51,800-cfs riverflow, a downbound tow would be required to have sufficient power to drive above the speed of the currents to maintain steerage until it is aligned with the right bank about two tow lengths upstream of the guard wall and to stop the tow in the lock approach (Photo 58). A low-powered tow could approach the lock by flanking around the bend upstream of the lock, move in against the bank and move along the bank line to enter the lock forebay.

Downbound tows could exit the lower lock approach with the 12,000-, 25,000-, and 51,800-cfs riverflows without any difficulties (Photos 60 - 62). The clockwise eddy that formed in the lower lock approach would move the tow away from the guide wall as it moved out of the approach. The tow would encounter some erratic currents downstream of the dike field but the tow would be clear of any structures. Upbound tows approaching the lock would encounter the same erratic currents downstream of the dike field but there was sufficient clearance to maneuver and control the tow. With a riverflow of 12,000 cfs, an upbound tow could approach the lower guide wall, align with the lock chamber, and enter the lock with a minimum of maneuvering (Photo 63). As the riverflow increased and the intensity of the eddy in the lower lock approach increased, there was a tendency for the clockwise eddy to move the head of the tow away from the guide wall (Photos 64 and 65). However, the tow could drive the head of the tow to the wall, attach a line to the wall, push the tow around to align with the chamber, and enter the lock. With the 25,000-cfs riverflow, this maneuver may not be required, but with the 51,800-cfs riverflow, this type of maneuver or some type of assistance would be required for the tow to align with the wall.

### **Experiments with the second stage of the dam cofferdam**

**Description.** The 175-ft-wide modified navigation pass was selected as the recommended plan for construction of the first section of the dam. The second stage of the dam cofferdam was constructed adjacent to the lock and extended riverward to encompass the river end of the completed part of the dam. During this phase of construction, flow would pass over a 223-ft-wide section of the partially completed dam. The top of the cofferdam cells upstream of the dam were at el 793.0 and the top of the cells downstream of the dam were at el 785.0.

**Water-surface elevations.** Water-surface elevations obtained with the second stage of the cofferdam in place are shown in Tables 12 and 13. These data show that with the lock closed (Table 12) the water-surface elevations upstream of the dam are considerably higher than those with Plan B Modified (Table 7) due to the limited width of the dam that passes flow. The increase in water-surface elevation varied from about 7.3 ft to 4.2 ft with the 107,500- and 197,000-cfs riverflows, respectively. When the water-surface elevations upstream of the dam exceeded the lock wall elevation (el 792.5) and flow started moving across the lock, the backwater effect decreased somewhat. The drop across the dam varied from about 19.9 to 7.3 ft with the 6,000- and 197,000-cfs riverflows, respectively.

To reduce the backwater effect with the higher riverflows, the lock gates were opened to pass flow with riverflows of 51,800-cfs and above (Table 13). These data show opening the gates would reduce the upstream elevations considerably compared with the lock gates being closed. The decrease in water-surface elevations upstream of the dam varied from about 7.3 ft to 1.8 ft with the 51,800- and 197,000-cfs riverflows, respectively. Comparing these data to modified Plan B (Table 7) shows the water-surface elevation upstream of the dam would decrease about 1.3 ft with the 51,800-cfs riverflow and increase about 2.4 ft with a riverflow of 107,500 cfs and above. The drop across the dam varied from about 10.6 ft to 6.2 ft with the 51,800- and 197,000-cfs riverflows, respectively.

**Current directions and velocities.** Current directions and velocities obtained with the second stage of the cofferdam in place are shown in Plates 49 - 52. These data show the currents are generally parallel to the right bank from the upstream end of the model to a point about 400 ft upstream of the upstream end of the guard wall. At that point, the currents turn toward the left bank to pass around the second stage of the dam cofferdam. The riverflow drops over the completed part of the dam, expands toward the lock, moves across the lower approach of the lock, and reattaches to the right bank from 600 to 1,200 ft downstream of the guide wall depending on the riverflow. A large clockwise eddy formed in the upper lock approach. The velocity of the upstream currents varied from less than 0.5 fps with the 12,000-cfs riverflow to about 0.5 fps with the 51,800-cfs riverflow. A large eddy formed downstream of the cofferdam and with the 25,000- and 51,800-cfs riverflows it extended downstream into the lower approach of the lock. The velocity of the upstream currents was as high as 2.0 fps with the 51,800-cfs riverflow. The maximum velocity of the currents that would affect tows entering and leaving the upper lock approach varied about 1.0 to 2.3 fps near the upstream end of the model, 1.1 to 2.5 fps about 3,500 ft upstream of the dam, and 1.2 to 1.8 fps near the upstream end of the guard wall with the 12,000- and 51,800-cfs riverflows, respectively.

The maximum velocity of the currents that would affect tows entering and leaving the lower lock approach varied from a downstream velocity of about 0.6 fps to an upstream velocity of 2.0 fps near the downstream end of the guide wall, 2.8 to 8.2 fps about 3,000 ft downstream of the dam, and 2.3 to 6.1 fps near the downstream end of the model with the 12,000- and 51,800-cfs riverflows, respectively.

**Spot velocities.** Point velocities were measured with a velocity meter in areas that were determined susceptible to scouring due to high velocities (Plates 53 and 54). With riverflows through 51,800 cfs, the lock would be closed to allow tows to lock through the project. With riverflows above 51,800 cfs, the lock gates were opened to pass flow, and all navigation through the reach would cease. With the 51,800-cfs riverflow, measurements were made with the lock closed and open. These data show that with the lock closed (Plate 53), the velocity of the currents exceeded 5.0 fps along the left bank downstream of the dam with a maximum velocity of about 7.8 fps occurring with the 51,800-cfs riverflow. The highest velocities along the river face of the cofferdam tended to occur upstream of the dam, where maximum velocity of the

currents along the river face of the cofferdam varied from about 2.9 to 7.5 fps with the 51,800- and 168,000 cfs riverflows, respectively.

**Navigation conditions.** Navigation conditions were satisfactory for tows entering and leaving the upper lock approach with all riverflows evaluated. With the 6,000- and 12,000-cfs riverflows, downbound tows could drive around the bend upstream of the lock, align with the guard wall about two tow lengths upstream of the wall, and land on the guard wall without any difficulties. With the 25,000-cfs riverflow, some maneuvering would be required for the tow to navigate the bend upstream of the lock and align with the guard wall. As the riverflow increased to 51,800-cfs, downbound tows were required to make a flanking maneuver to navigate the bend upstream of the lock and align with the guard wall. Navigation conditions were satisfactory for tows entering and leaving the lower lock approach with riverflows through 25,000 cfs. However, as the riverflow increased to 51,800 cfs, the eddy in the lower approach of the lock created some difficulties for tows entering and leaving the lower lock approach. Downbound tows had some difficulties holding the tow on the lower guide wall and exiting the lock chamber without being rotated and pinned in the lock chamber. Navigation conditions for upbound tows approaching the lock could be hazardous. Upbound tows experienced erratic high-velocity currents approaching the lock and there was a tendency for the tow to be moved into the guide wall with considerable force. As the tow moved up along the guide wall to enter the lock chamber, the head of the tow was moved riverward by the eddy and the tow was rotated in the lock approach. There was an indication the head of the tow could be moved riverward of the approach into the high-velocity currents passing through the navigation pass and be swept downstream into the left bank or the stern of the towboat being grounded on the right bank.

#### **Conclusions and recommendations:**

- a. With the first stage of the modified dam cofferdam, the design size tow can safely navigate the 170-ft effective width navigation pass between the cofferdam and the lock with a riverflow of 6,000 cfs. However, a tow of this size should approach the navigation pass with proper caution.
- b. With a riverflow of 9,000 cfs, the current alignment approaching and exiting the navigation pass was satisfactory for upbound and downbound tows to bypass the lock. However, due to the magnitude of the velocities in the pass and the cross-sectional area blocked by the design size tow as it moves through the pass, average powered upbound tows may not be able to push the design size tow through the pass.
- c. As the riverflow increases to 12,000 cfs, the velocities of the currents in the navigation pass would require a high-powered towboat to push the design size tow upstream through the navigation pass. Although a downbound tow could approach and enter the navigation pass, the tendency for the currents to push the tow into the left bank dikes would make it unsafe for a tow to navigate through the pass.

- d. Tows could safely enter and exit the upper lock approach with riverflows of 12,000, 25,000, and 51,800 cfs. However, the upper lock approach was restricted due to the elevation of the excavation along the right descending bank approaching the lock. The depth of water over the right bank excavation did not provide navigation depth for a tow drafting 9.0 ft except with the 51,800-cfs riverflow. This could cause delays at the lock due to the maneuvering required for the tow to enter the lock forebay. It is recommended that the channel be marked with buoys so tows can move as close to the right bank as possible when approaching the lock.
- e. The guard wall cells would be exposed to the barges with the 12,000- and 25,000-cfs riverflows due to the normal upper pool not being established. The cells could be subjected to considerable damage from tows striking the cells. It is recommended that a temporary rubbing surface be provided to allow tows to move along the cells without damaging the cells.
- f. Tows could safely enter and exit the lower lock approach with all flows evaluated. However, tows will experience erratic currents downstream of the left bank dike field and a clockwise eddy in the lower approach of the lock. Upbound tows approaching the lock could maneuver through the eddy and approach the guide wall. At the higher flows, the tow may be required to put the head of the tow on the guide wall, tie a line to the wall, and push the tow around to align with the lock chamber.
- g. Although the left bank dikes reduce the size and intensity of the eddy that forms in the lower lock approach, they do not eliminate the eddy or all of the adverse effects of the eddy on tows using the lock. Dikes could probably be developed to eliminate the eddy in the lower lock approach; however, with the higher riverflows the downstream velocities moving across the lower lock approach could increase to the point that downbound tows would experience difficulties breaking free of the guide wall and moving downstream.

## **Experiments During Construction of the First Stage of the Dam Cofferdam**

### **Discussion and purpose of experiments**

Model experiments were conducted with the model simulating three intermediate stages of construction for the first stage of the dam cofferdam to evaluate navigation conditions for tows passing through the project during the construction period. All three intermediate phases of cofferdam construction were evaluated with riverflows of 6,000, 12,000, 25,000, and 51,800 cfs. The Phase 3 condition was also evaluated with the 9,000-cfs riverflow to determine the maximum riverflow at which a tow could safely navigate past the lock. Movement of a model tow representing the design size tow (six 35-ft-wide by 195-ft-long barges with a 120-ft-long towboat for a total size of 70 ft wide by



705 ft long) navigating the reach with a range of riverflows was documented with a video tracking system to illustrate the navigation conditions.

## **Phase 1 experiments**

Phase 1 conditions were the same as with the lock cofferdam in place as previously described, except most of the lock cofferdam was removed, leaving 18 riverward cells as shown on Figure 15.

## **Results**

**Current direction and velocities.** Current direction and velocity data taken with Phase 1 conditions are shown in Plates 55 - 58. These data indicate that with all riverflows evaluated the currents are generally parallel, with the right descending bank approaching the upper guard wall of the lock, angling riverward to move around the lock and the remaining part of the lock cofferdam, and then turning toward the right descending bank immediately downstream of the lock. The maximum velocity of the currents in the vicinity of the lock varied from about 1.7 fps with the 6,000-cfs riverflow to about 7.1 fps with the 51,800-cfs riverflow. These maximum velocities occurred near the downstream end of the remaining part of the lock cofferdam.

**Navigation conditions.** Navigation experiments were conducted with all riverflows; however, all of the experiments were not documented with tow path data. Tow paths moving past the lock with the 6,000- and 51,800-cfs riverflows are shown in Plates 59 - 62. These data indicate downbound and upbound tows could move past the lock without any major difficulties with all riverflows evaluated.

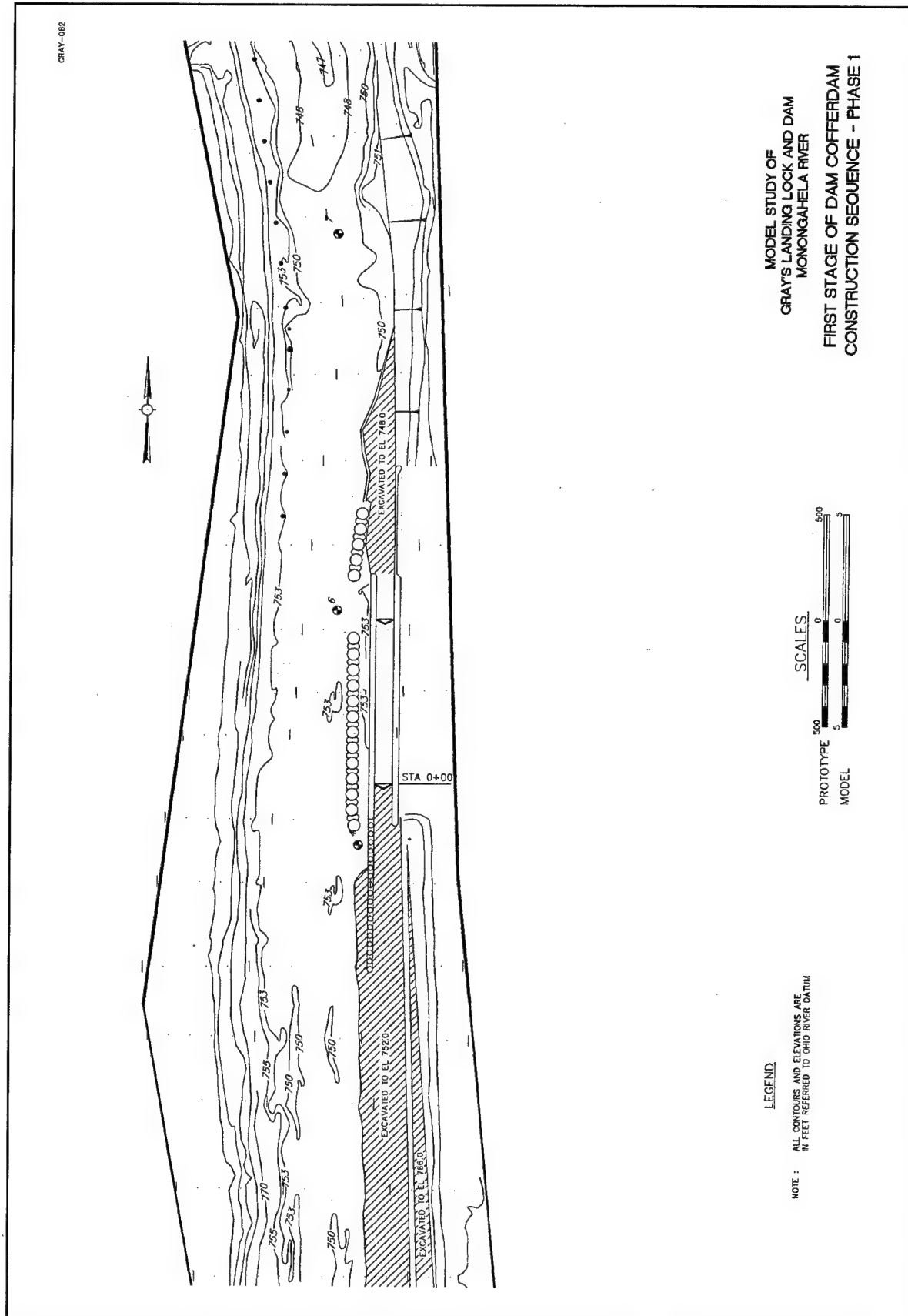
## **Phase 2 Experiments**

Phase 2 was the same as Phase 1, except: (a) the eight most upstream cells of the remaining portion of the lock cofferdam were removed, leaving five cells in the vicinity of the first stage of the dam cofferdam; (b) three cells of the upstream leg and two cells of the downstream leg of the first stage of the dam cofferdam were constructed adjacent to the left descending bank (Figure 16); and (c) a 35-ft-wide by 195-ft-long work barge was moored along the remaining portion of the lock cofferdam.

## **Results**

**Current direction and velocities.** Current direction and velocity data taken with Phase 2 conditions are shown in Plates 63 - 66. These data indicate the currents are generally parallel with the right descending bank approaching the guard wall of the lock, angle riverward slightly to move around the guard wall,





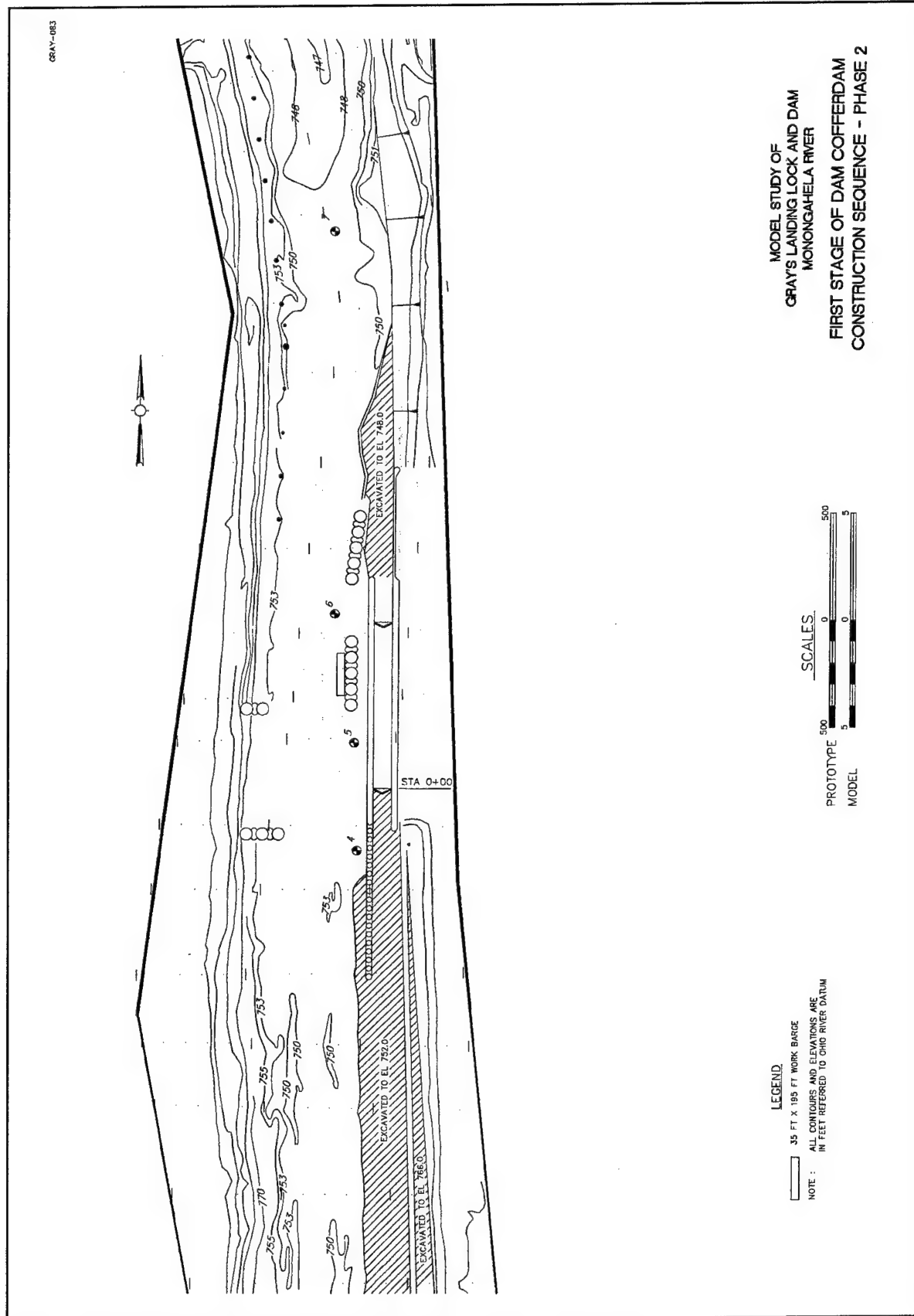


Figure 16. First stage of dam cofferdam construction sequence, Phase 2

change direction slightly several times as the currents move past the upstream leg of the dam cofferdam and the remaining part of the lock cofferdam, and move toward the right bank immediately downstream of the lock. A low-velocity counterclockwise eddy formed along the left descending bank immediately downstream of the upstream and downstream legs of the dam cofferdam. The completed parts of the dam cofferdam constricted the channel in the vicinity of the lock and increased the velocity of the currents moving through the reach. The maximum velocity of the currents in the vicinity of the lock varied from about 1.9 fps with the 6,000-cfs riverflow to about 8.4 fps with the 51,800-cfs riverflow. These maximum velocities occurred throughout most of the cofferdam construction area.

**Navigation conditions.** The paths of tows moving through the reach are shown on Plates 67 - 76. These data indicate navigation conditions were satisfactory for downbound and upbound tows navigating past the lock with riverflows through 25,000 cfs (Plates 67 - 72). As the riverflow increased to 51,800 cfs, the angle and velocity of the currents had a tendency to move a downbound tow into the lock or remaining part of the lock cofferdam (Plate 73). Considerable maneuvering and power would be required for an upbound tow to move past the restricted area and any error in judgment or alignment could result in the tow being moved into either the lock or one of the cofferdam cells (Plate 74). With the 51,800-cfs riverflow, navigation conditions were satisfactory for upbound and downbound tows using the new lock (Plates 75 and 76). However, it should be noted that the upper lock approach is restricted due to the 766.0-el excavation along the right descending bank approaching the lock. With the upper pool elevations occurring during this phase of construction, the depth over the right bank excavation will not accommodate a tow drafting 9.0 ft with the 51,800-cfs riverflow. It should also be noted that the rubbing surface of the guard wall will be above the water-surface elevation. A downbound tow would be required to have sufficient power to drive above the currents to maintain steerage until it is aligned with the right bank about two tow lengths upstream of the guard wall and to stop the tow in the lock approach. A low-powered tow could approach the lock by flanking around the bend upstream of the lock, moving in against the bank, and moving along the bank line to enter the lock forebay.

### Phase 3 experiments

Phase 3 was the same as Phase 2 except: (a) the three most upstream cells of the remaining portion of the lock cofferdam were removed, leaving two cells in the vicinity of the first stage of the dam cofferdam; (b) one additional cell was constructed adjacent to the upstream and downstream legs of the first stage of the dam cofferdam (Figure 17); and (c) a 35-ft-wide by 195-ft-long work barge was moored along the remaining portion of the lock cofferdam.

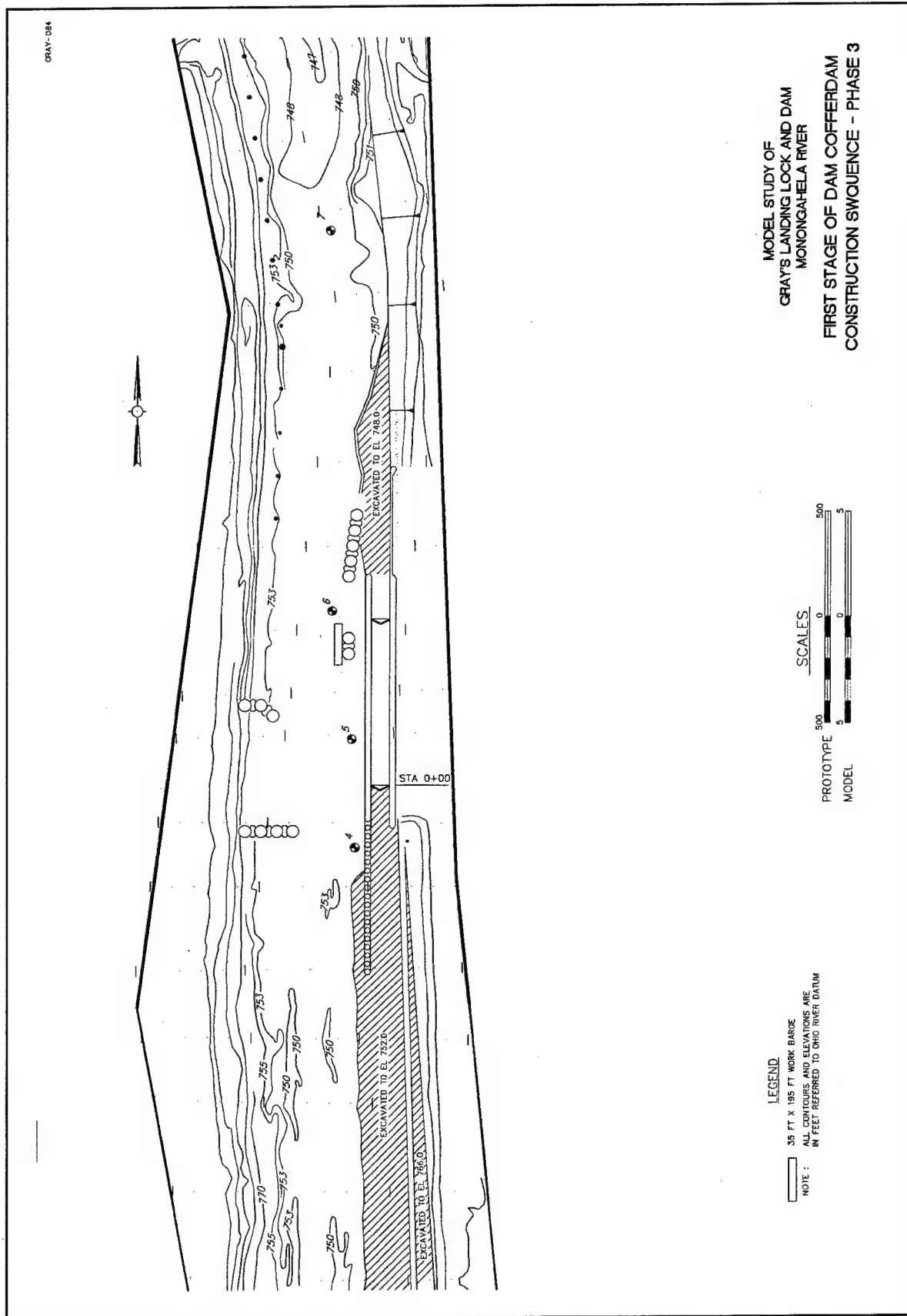


Figure 17. First stage of dam cofferdam construction sequence, Phase 3

## Results

**Current direction and velocities.** Current direction and velocity data indicate a significant increase in velocities and change in directions through the cofferdam reach as compared to Phase 1 or 2 (Plates 77 - 81). The currents are generally parallel with the right descending bank approaching the guard wall, angle riverward to move past the guard wall, angle to the right to move past the upstream leg of the dam cofferdam, expand toward the left bank immediately downstream of the upstream leg, and angle toward the right bank immediately downstream of the remaining part of the lock cofferdam. These conditions created changing current directions through the entire construction area. The maximum current velocities through the area varied from about 2.3 fps to about 10.7 fps with the 6,000- and 51,800-cfs riverflows, respectively. Maximum velocities occurred in the dam cofferdam area of the construction.

**Navigation conditions.** Tow paths through the reach are shown on Plates 82 - 93. These data indicate navigation conditions were satisfactory for downbound and upbound tows navigating past the lock with riverflows through 9,000 cfs (Plates 82 - 85), although considerable maneuvering would be required. With the 12,000-cfs riverflow, there was a tendency for the currents to push a downbound tow into the work barge moored along the remaining portion of the lock cofferdam (Plate 86). As the riverflow increased to 25,000 cfs, the angle and velocity of the currents had a tendency to move a downbound tow into the lock (Plate 88). Considerable maneuvering and power were required for an upbound tow to navigate past the lock and any error in judgment or alignment could result in the tow being moved into either the lock or the cofferdam cells (Plate 89). With the 25,000- and 51,800-cfs riverflows, upbound and downbound tows could move through the project, provided proper caution is taken approaching the lock (Plates 90 - 93). It should be noted that the upper lock approach is restricted due to the 766.0-el excavation along the right descending bank approaching the lock. There was not sufficient depth over the excavation for a tow drafting 9.0 ft. Therefore, a downbound tow was required to have sufficient power to drive above the speed of the currents to maintain steerage until it was aligned with the right bank about two tow lengths upstream of the guard wall and to stop the tow in the approach. A low-powered tow could approach the lock by flanking around the bend upstream of the lock, moving in close to the bank and moving along the bank, to enter the lock forebay.

### Conclusions and recommendation:

- a. With Phase 1 conditions, downbound and upbound tows can move past the lock without any major difficulties.
- b. With Phase 2 conditions, tows can move past the lock with riverflows through 25,000 cfs. Tows can lock through the reach with the 51,800-cfs riverflow.

- c.* With Phase 3 conditions, tows can move past the lock with riverflows through 9,000 cfs. Tows can lock through the reach with riverflows above 9,000 cfs without any major difficulties.
- d.* With the upper pool elevations occurring during construction of the first stage of the dam cofferdam, the upper lock approach is restricted due to the 766.0 el excavation along the right descending bank approaching the lock. The depth of water over the right bank excavation did not provide navigation depth for a tow drafting 9.0 ft with any of the riverflows evaluated.
- e.* The guard wall cells would be exposed to the barges with all riverflows evaluated. The cells could be subjected to considerable damage from tows striking the cells unless a rubbing surface is provided to allow tows to move along the cells.

## **4 Discussion of Results and Conclusions**

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### **Limitations of Model Results**

Analysis of this investigation's results is based on a study of : (a) the effects of various plans and modifications on water-surface elevations and current directions and velocities, and (b) the effects of the resulting currents on model towboat and tow behavior. In evaluating the results, it should be taken into consideration that small changes in current directions and velocities are not necessarily changes produced by a modification in the plan, since several floats introduced at the same point may follow a different path and move at somewhat different velocities due to pulsating currents and eddies. Current directions and velocities shown in the plates were obtained with floats submerged to the depth of a loaded barge (9-ft prototype) and are more indicative of currents affecting the behavior of tows than those indicated by photographs, which indicate the movement of confetti on the water surface and could be affected by surface tension.

The small scale of the model made it difficult to reproduce accurately the hydraulic characteristics of the prototype structures or to measure water-surface elevation with an accuracy greater than about  $\pm 0.1$  ft prototype. Also, current directions and velocities were based on steady riverflows and would be somewhat different with varying riverflows. The model was a fixed-bed type and not designed to reproduce overall sediment movement that might occur in the prototype with the various plans. Therefore, changes in channel configuration resulting from scouring and deposition and any resulting changes in current directions and velocities were not evaluated.

### **Summary of Results and Conclusions**

The following results and conclusions were developed during the investigation:

- a. Satisfactory navigation conditions cannot be developed for all riverflows with the lock located at the originally proposed position (the original design through Plan A modified). The lock was too close to the bend for a downbound tow to make the turn and align with the lock approach without some type of flanking maneuver.
- b. Moving the lock and dam downstream about 1,000 ft (as shown in Plan B) provided additional maneuvering area for downbound tows to navigate the bend upstream of the lock and align with the upper guard wall.
- c. A submerged dike scheme similar to those shown in Plans B and B Modified is required to provide satisfactory navigation conditions for downbound tows approaching the lock with the full range of riverflows.
- d. Removing the original icebreaker cells and constructing a new smaller structure farther downstream similar to Plan B Modified would improve navigation conditions for tows entering and leaving the lower lock approach when compared with Plan B.
- e. Plan B Modified provided satisfactory navigation conditions for tows entering and leaving the lock with all riverflows through the maximum navigable riverflow of 107,500 cfs.
- f. With the lock cofferdam in place, navigation conditions were unsatisfactory with the original icebreaker cells in place. Navigation conditions were satisfactory for tows navigating past the cofferdam with the icebreaker cells removed.
- g. A 125-ft-wide navigation pass between the lock and the first stage of the dam cofferdam will not provide satisfactory navigation conditions through the pass, even with the lowest riverflows.
- h. A 175-ft-wide navigation pass between the lock and the first stage of the dam cofferdam provided satisfactory navigation conditions with riverflows through 12,000 cfs.
- i. A 225-ft-wide navigation pass between the lock and the first stage of the dam cofferdam provided satisfactory navigation conditions with riverflows through 25,000 cfs.
- j. The 175-ft-wide navigation pass modified plan, with its system of spur dikes along the left bank downstream of the cofferdam and guard wall port closure scheme, provides satisfactory navigation conditions for tows navigating the pass with riverflows through 9,000 cfs. With riverflows of 12,000, 25,000, and 51,800 cfs, tows could enter and leave the lock approaches without any major difficulties.
- k. With the second stage of the dam cofferdam, navigation conditions were satisfactory for tows entering and leaving the lock approaches with all riverflows evaluated.





**Table 2**  
**Modified Original Design**

**Water-Surface Elevations (ft NGVD)**

Gauge No.	Discharge in 1,000 CFS		
	51.8	73	107.5
1	786.7	788.6	791.7
2	786.6	788.5	791.5
3	786.6	788.4	791.4
4	786.5	788.3	791.3
Axis of Dam			
5 <sup>1</sup>	775.0	779.3	785.6
6	774.6	778.8	785.4
7	774.3	778.5	784.9
8	774.3	778.5	784.9
Head/Dam (G4 - G5)	11.5	9.0	5.7
Slope 1-4 (ft/0.8 mi)	0.2	0.4	0.5
Slope 5-8 (ft/1.0 mi)	0.7	0.8	0.7

<sup>1</sup> Controlled elevations.

**Table 3**  
**Plan A**

**Water-Surface Elevations (ft NGVD)**

Gauge No.	Discharge in 1,000 CFS		
	51.8	73	107.5
1	786.7	788.7	791.7
2	786.6	788.6	791.5
3	786.6	788.4	791.5
4	786.5	788.3	791.3
Axis of Dam			
5 <sup>1</sup>	775.0	779.3	785.6
6	774.6	778.8	785.4
7	774.3	778.5	784.9
8	774.3	778.5	784.9
Head/Dam (G4 - G5)	11.5	9.0	5.7
Slope 1-4 (ft/0.8 mi)	0.2	0.5	0.5
Slope 5-8 (ft/1.0 mi)	0.7	0.8	0.7
<sup>1</sup> Controlled elevations.			

**Table 4**  
**Plan A Modified**

**Water-Surface Elevations (ft NGVD)**

Gauge No.	Discharge in 1,000 CFS		
	51.8	73	107.5
1	786.6	788.6	791.7
2	786.6	788.5	791.6
3	786.6	788.5	791.5
4	786.5	788.3	791.3
Axis of Dam			
5 <sup>1</sup>	775.0	779.3	785.6
6	774.6	778.8	785.4
7	774.3	778.5	784.9
8	774.3	778.5	784.9
Head/Dam (G4 - G5)	11.5	9.0	5.7
Slope 1-4 (ft/0.8 mi)	0.1	0.4	0.5
Slope 5-8 (ft/1.0 mi)	0.7	0.8	0.7

<sup>1</sup> Controlled elevations.

**Table 5**  
**Plan B**

**Water-Surface Elevations (ft NGVD)**

Gauge No.	Discharge in 1,000 CFS							
	51.8	73	102	107.5	123.5	157	168	197
1	786.5	788.4	790.9	791.5	793.2	797.7	799.1	802.0
2	786.4	788.3	790.8	791.2	792.9	797.3	798.8	801.7
3	786.3	788.2	790.6	791.1	792.7	797.2	798.7	801.5
4	786.2	788.0	790.4	790.9	792.4	797.0	798.5	801.3
Axis of Dam								
5 <sup>1</sup>	775.0	779.3	784.5	785.6	788.3	793.3	794.7	798.8
6	774.8	779.2	784.4	785.5	788.1	793.1	794.4	798.6
7	774.3	778.7	783.8	784.8	787.3	792.6	793.8	797.9
8	774.3	778.7	783.8	784.7	787.3	792.6	793.7	797.9
Head/Dam (G4 - G5)	11.2	8.7	6.1	5.3	4.1	3.7	3.8	2.5
Slope 1-4 (ft/1.0 mi)	0.3	0.4	0.5	0.6	0.8	0.7	0.6	0.7
Slope 5-8 (ft/0.8 mi)	0.9	0.8	0.8	1.1	1.2	0.9	1.2	1.1

<sup>1</sup> Water-surface elevations were controlled at Gauge 5 to tailwater rating curve supplied by Pittsburgh District.

**Table 6**  
**Modified Plan B with New Ice Breaker Cells**

**Water-Surface Elevations (ft NGVD)**

Gauge No.	Discharge in 1,000 CFS							
	51.8	73	102	107.5	123.5	157	168	197
1	786.5	788.4	790.9	791.5	793.2	797.7	799.1	802.0
2	786.4	788.3	790.8	791.2	792.9	797.3	798.8	801.7
3	786.3	788.2	790.6	791.1	792.7	797.2	798.7	801.5
4	786.2	788.0	790.4	790.8	792.4	797.0	798.5	801.3
Axis of Dam								
5	774.8	779.2	784.3	785.2	787.7	792.8	794.6	798.4
6	774.7	779.0	784.1	785.1	787.5	792.6	794.4	798.2
7 <sup>1</sup>	774.5	778.7	783.8	784.8	787.4	792.4	794.2	798.0
8	774.4	778.7	783.8	784.7	787.3	792.4	794.2	797.9
Head/Dam (G4 - G5)	11.4	8.8	6.1	5.6	4.7	4.2	3.9	2.9
Slope 1-4 (ft/1.0 mi)	0.3	0.4	0.5	0.7	0.8	0.7	0.6	0.7
Slope 5-8 (ft/0.8 mi)	0.5	0.6	0.6	0.6	0.5	0.5	0.5	0.6

<sup>1</sup> Control of water-surface elevations was moved to Gauge 7 at the request of Pittsburgh District.

**Table 7**  
**Modified Plan B without New Ice Breaker Cells**

Water-Surface Elevations (ft NGVD)								
Gauge No.	Discharge in 1,000 CFS							
	51.8	73	102	107.5	123.5	157	168	197
1	786.5	788.4	790.9	791.5	793.2	797.7	799.1	802.0
2	786.4	788.3	790.8	791.2	792.9	797.3	798.8	801.7
3	786.3	788.2	790.6	791.1	792.7	797.2	798.7	801.5
4	786.2	788.0	790.4	790.8	792.4	797.0	798.5	801.3
Axis of Dam								
5	774.7	779.1	784.2	785.1	787.6	792.6	794.4	798.4
6	774.6	778.9	784.0	785.0	787.4	792.5	794.2	798.2
7	774.5	778.7	783.8	784.8	787.4	792.4	794.2	798.0
8 <sup>1</sup>	774.4	778.7	783.8	784.7	787.3	792.4	794.2	797.9
Head/Dam (G4 - G5)	11.4	8.8	6.1	5.6	4.7	4.2	3.9	2.9
Slope 1-4 (ft/1.0 mi)	0.3	0.4	0.5	0.7	0.8	0.7	0.6	0.7
Slope 5-8 (ft/0.8 mi)	0.4	0.5	0.5	0.5	0.4	0.3	0.3	0.6

<sup>1</sup> Controlled elevation.

**Table 8****Plan B Modified, without New Ice Breaker Cells, Lock Open****Water-Surface Elevations (ft NGVD)**

Gauge No.	Discharge in 1,000 CFS		
	157	168	197
1	795.8	797.4	800.8
2	795.4	797.1	800.5
3	795.3	796.8	800.4
4	795.3	796.8	800.4
Axis of Dam			
5	792.7	794.4	798.4
6	792.7	794.3	798.3
7	792.5	794.2	798.1
8 <sup>1</sup>	792.4	794.1	798.0
Head/Dam (G4 - G5)	2.6	2.4	2.0
Slope 1-4 (ft/1.0 mi)	0.5	0.6	0.4
Slope 5-8 (ft/0.8 mi)	0.4	0.4	0.5

<sup>1</sup> Controlled elevations.



**Table 9****Plan B Modified, Lock Cofferdam, with Existing Icebreaker Cells****Water-Surface Elevations (ft NGVD)**

<b>Gauge No.</b>	<b>Discharge in 1,000 CFS</b>				
	<b>25</b>	<b>51.8</b>	<b>107.5</b>	<b>157</b>	<b>197</b>
1	769.4	776.1	787.5	795.4	800.9
2	769.3	776.0	787.4	795.2	800.7
3	769.2	775.9	787.2	795.1	800.5
4	768.9	775.4	786.5	794.3	799.9
<b>Axis of Dam</b>					
5	768.8	775.3	786.4	794.0	799.5
6	768.7	775.1	786.0	793.7	799.2
7	768.4	774.3	784.5	792.2	797.8
8 <sup>1</sup>	768.3	774.4	784.8	792.4	798.0
Head/Structure (G4 -G6)	0.2	0.3	0.5	0.6	0.7
Slope 1-4 (ft/1.0 mi)	0.5	0.7	1.0	1.1	1.0
Slope 5-8 (ft/0.8 mi)	0.6	1.1	2.0	2.0	1.9
<sup>1</sup> Controlled elevations.					

**Table 10**  
**Plan B Modified, Lock Cofferdam, without Existing Icebreaker Cells**

**Water-Surface Elevations (ft NGVD)**

Gauge No.	Discharge in 1,000 CFS				
	25	51.8	107.5	157	197
1	769.2	775.7	786.4	794.4	800.0
2	769.1	775.6	786.3	794.2	799.8
3	769.0	775.4	786.1	794.0	799.6
4	768.7	775.0	785.4	793.2	798.9
<b>Axis of Dam</b>					
5	768.6	774.8	785.2	792.9	798.4
6	768.5	774.6	786.0	792.5	798.2
7	768.4	774.5	784.8	792.4	798.0
8 <sup>1</sup>	768.3	774.4	784.8	792.4	798.0
Head/Structure (G4 -G6)	0.2	0.4	0.4	0.7	0.7
Slope 1-4 (ft/1.0 mi)	0.5	0.7	1.0	1.2	1.1
Slope 5-8 (ft/0.8 mi)	0.4	0.5	0.5	0.6	0.5

<sup>1</sup> Controlled elevations.

**Table 11**  
**Modified Plan B, First Stage of Dam Cofferdam, 175-ft-wide Modified**  
**Navigation Pass**

Water-Surface Elevations (ft NGVD)						
Gauge No.	Discharge in 1,000 CFS					
	6	9	12	25	51.8	107.5
1	764.3	765.1	766.4	770.4	778.5	792.3
2	764.2	765.1	766.3	770.2	778.5	792.2
3	764.2	765.1	766.3	770.2	778.4	792.1
4	764.1	764.9	765.9	769.5	777.0	789.6
Axis of Dam						
5	764.0	764.7	765.3	768.6	775.1	786.1
6	763.9	764.6	765.0	768.2	773.9	783.1
7	763.9	764.5	765.0	768.3	774.3	784.8
8 <sup>1</sup>	763.9	764.5	765.0	768.3	774.4	784.8
Head/Structure (G3 -G6)	0.3	0.5	1.3	2.0	4.5	9.0
Slope 1-4 (ft/1.0 mi)	0.1	0.2	0.5	0.9	1.5	2.7
Slope 5-8 (ft/0.8 mi)	< 0.1	0.3	0.4	0.4	0.9	1.6
<sup>1</sup> Controlled elevations.						

**Table 12**  
**Second Stage of the Dam Cofferdam (Lock Closed)**

**Table 13**  
**Second Stage of the Dam Cofferdam (lock open)**

Water-Surface Elevations (ft NGVD)					
Gauge No.	Discharge in 1,000 CFS				
	51.8	107.5	157	168	197
1	785.0	793.4	799.5	801.2	803.9
2	784.9	793.1	799.4	801.1	803.7
3	784.9	793.0	799.3	800.9	803.7
4	784.9	793.2	799.4	801.1	803.7
Axis of Dam					
5	774.3	784.4	791.8	793.6	797.5
6	774.4	784.4	792.0	794.0	798.0
7	774.4	784.8	792.4	794.2	798.1
8 <sup>1</sup>	774.4	784.8	792.4	794.1	798.0
Head/dam (G4 -G5)	10.6	8.8	7.5	7.5	6.2
Slope 1-4 (ft/1.0 mi)	0.1	0.2	0.1	0.1	0.2
Slope 5-8 (ft/0.8 mi)	0.0	0.0	0.0	0.0	0.0
<sup>1</sup> Controlled elevations.					

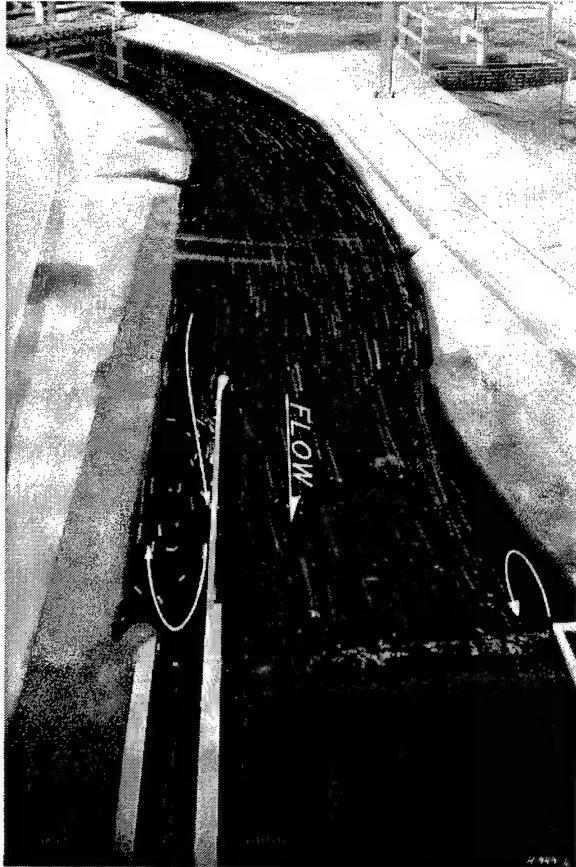
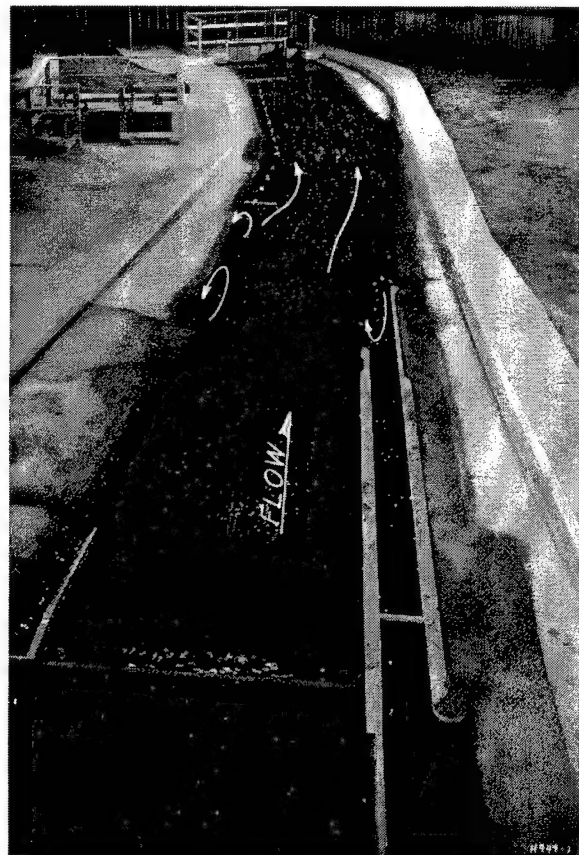


Photo 1. Original design, looking upstream;  
discharge 51,800 cfs; confetti showing surface  
current patterns

Photo 2. Original design, looking downstream;  
discharge 51,800 cfs; confetti showing surface  
current patterns



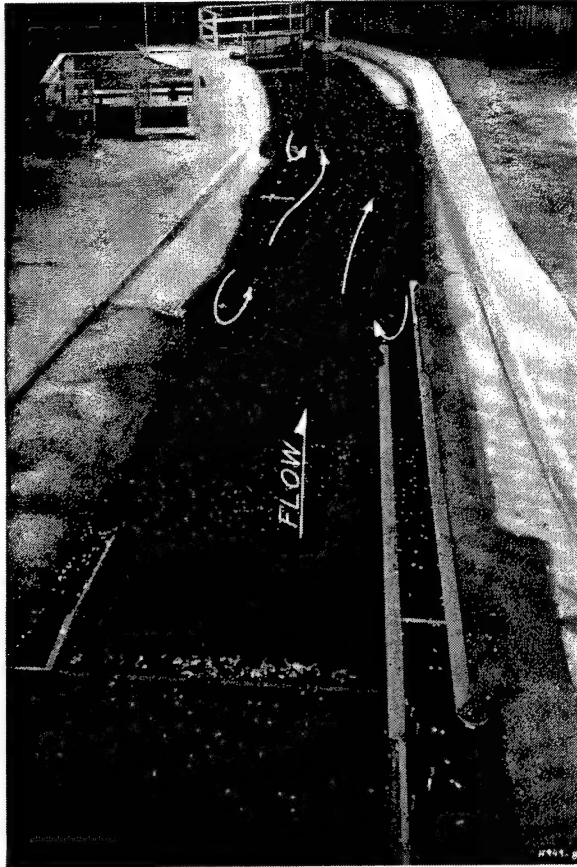


Photo 3. Original design, looking downstream; discharge 107,500 cfs; confetti showing surface current patterns

Photo 4. Original design, looking upstream; discharge 51,800 cfs; showing path of down-bound tow flanking bend to approach lock



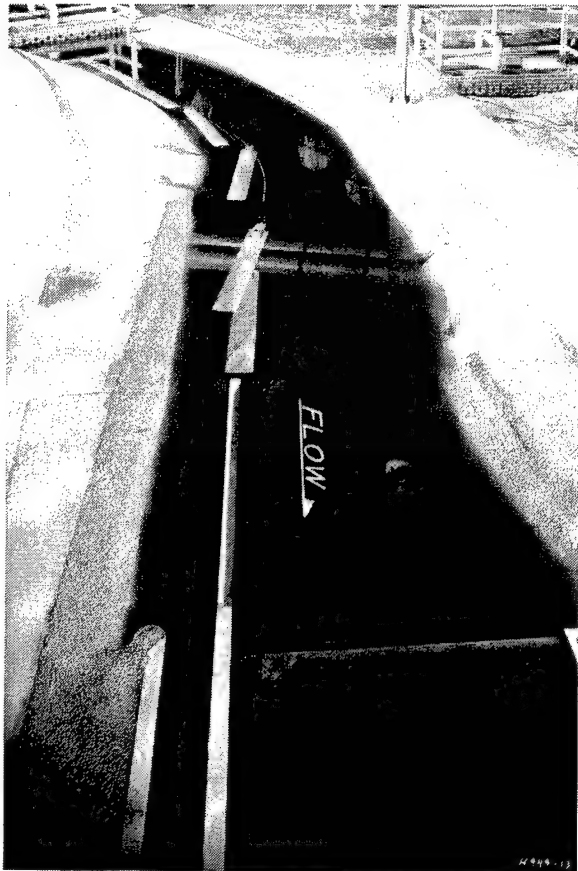
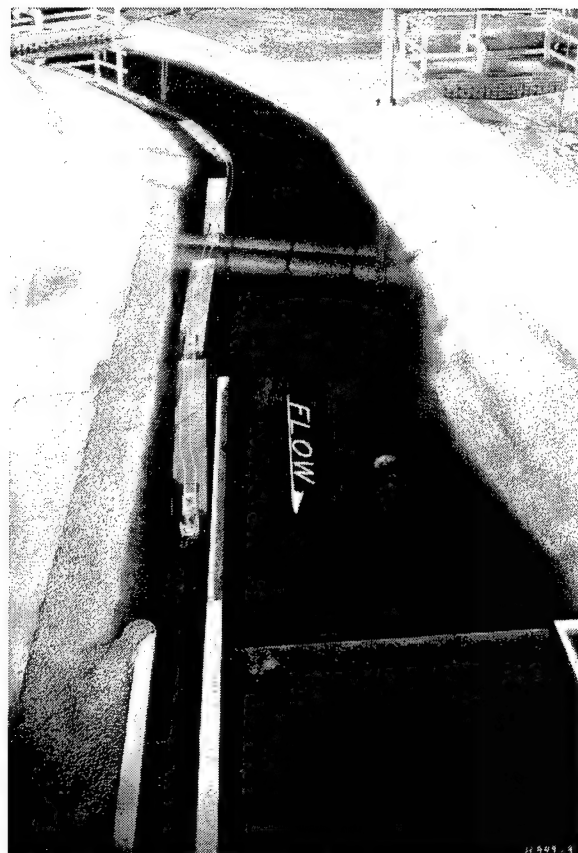


Photo 5. Original design, looking upstream; discharge 51,800 cfs; showing path of down-bound tow driving bend to approach lock

Photo 6. Original design, looking upstream; discharge 51,800 cfs; showing path of upbound tow leaving lock





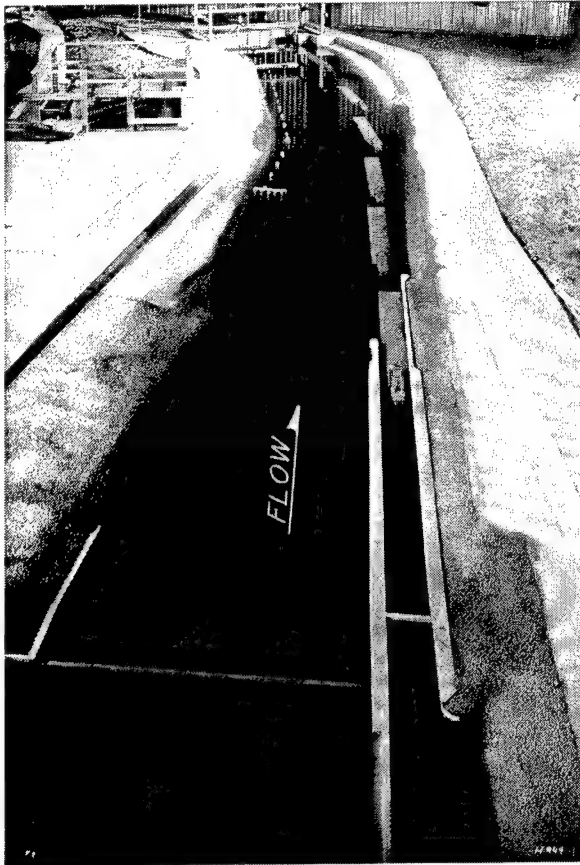
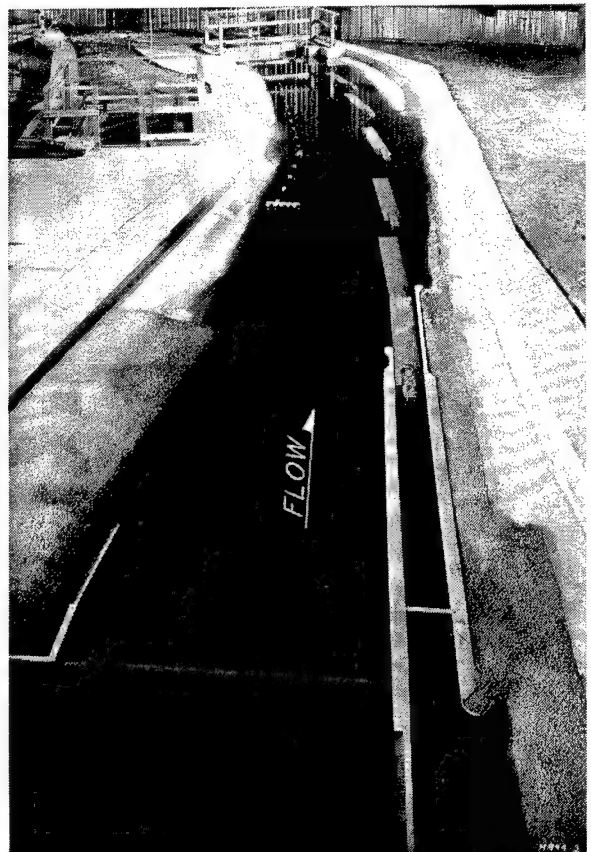


Photo 7. Original design, looking downstream; discharge 51,800 cfs; showing path of down-bound tow leaving lock

Photo 8. Original design, looking downstream; discharge 107,500 cfs; showing path of down-bound tow leaving lock



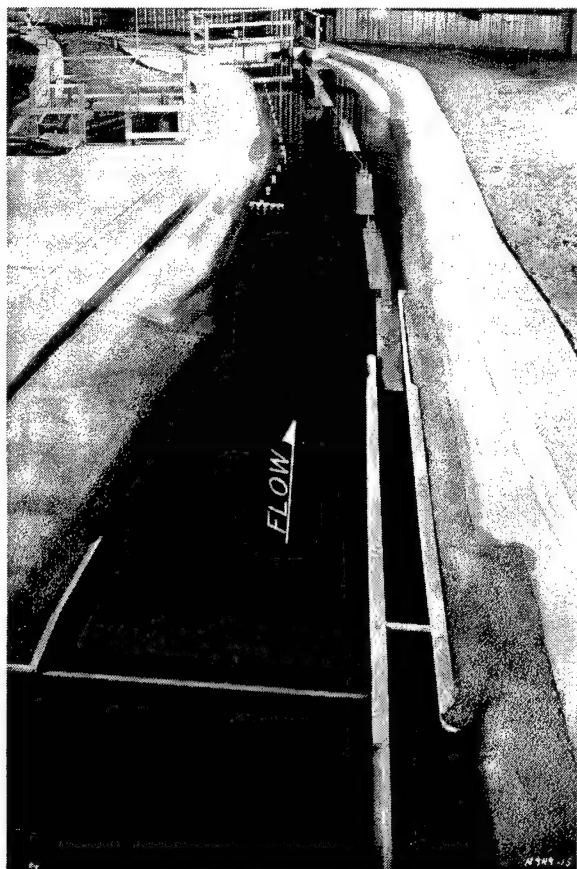


Photo 9. Original design, looking downstream; discharge of 51,800 cfs; showing path of upbound tow approaching lock

Photo 10. Original design, looking downstream; discharge of 107,500 cfs; showing path of upbound tow approaching lock

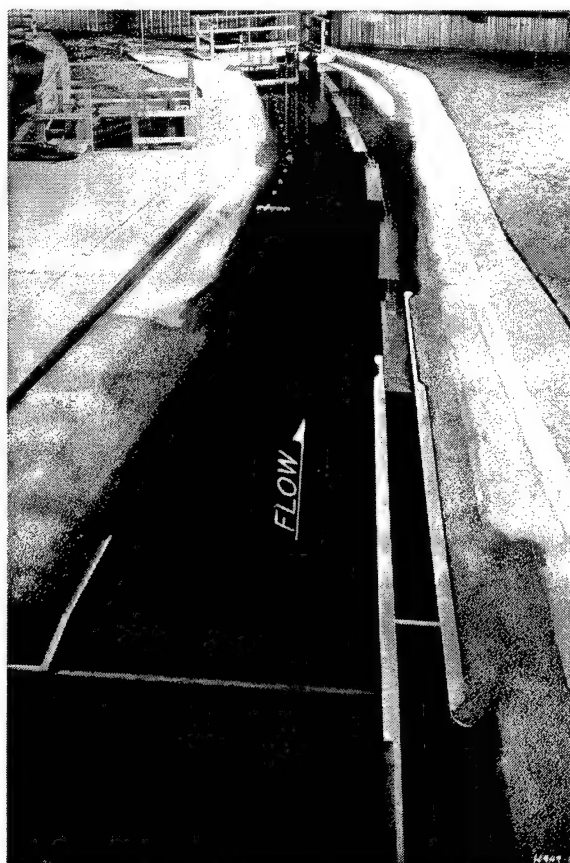




Photo 11. Original design modified, looking upstream; discharge of 51,800 cfs; confetti showing surface current patterns

Photo 12. Plan A modified, looking upstream; discharge of 107,500 cfs; confetti showing surface current patterns



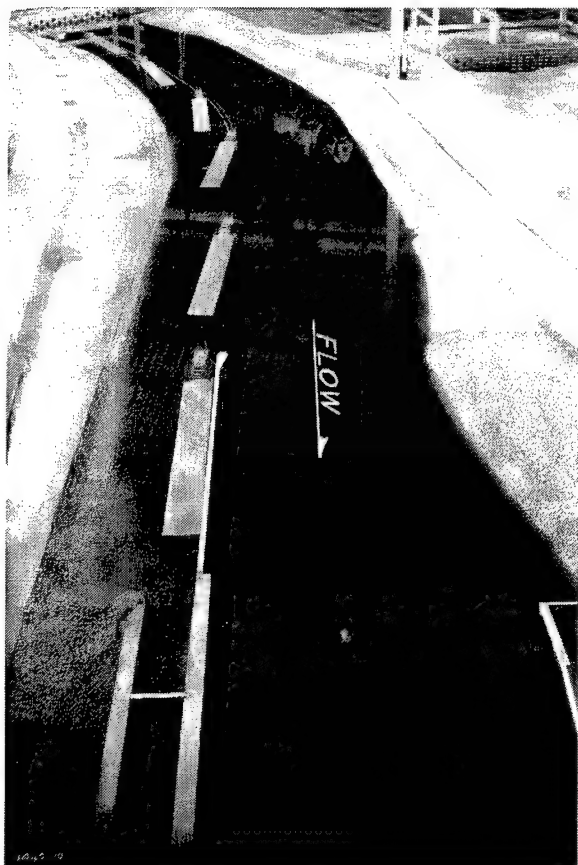


Photo 13. Plan A modified, looking upstream;  
discharge of 107,500 cfs; showing path of  
downbound tow approaching lock

Photo 14. Plan A modified, looking upstream;  
discharge of 107,500 cfs; showing path of  
upbound tow leaving lock



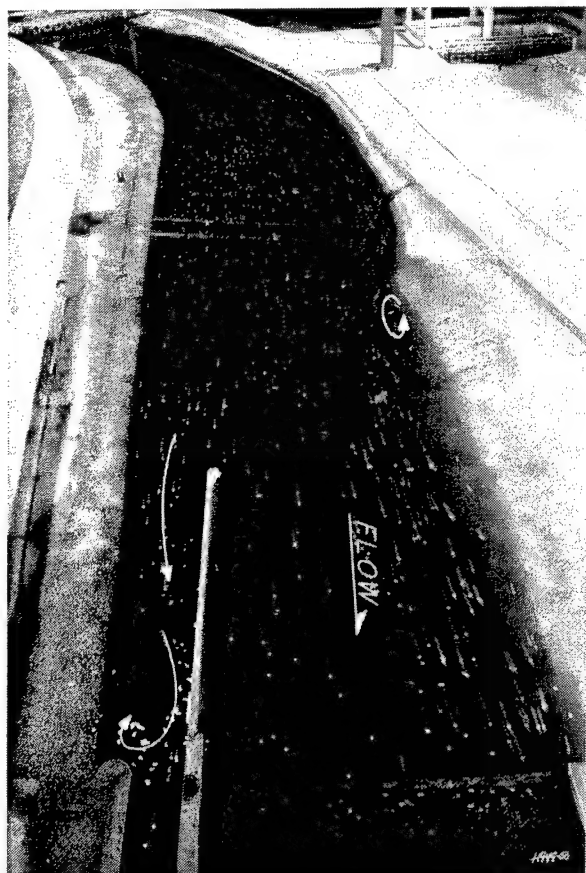


Photo 15. Plan B, looking upstream; discharge of 51,800 cfs; confetti showing surface current patterns

Photo 16. Plan B, looking downstream; discharge of 51,800 cfs; confetti showing surface current patterns



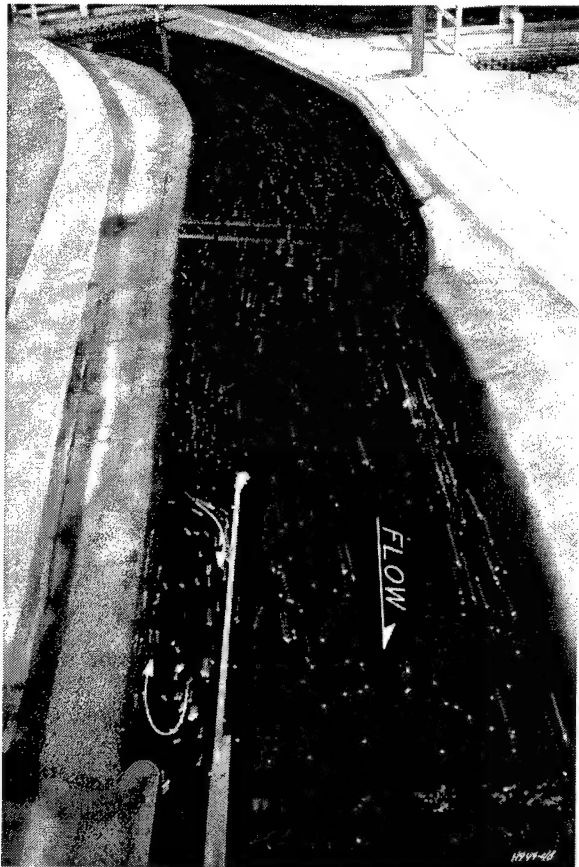


Photo 17. Plan B, looking upstream; discharge of 107,500 cfs; confetti showing surface current patterns

Photo 18. Plan B, looking downstream; discharge of 107,500 cfs; confetti showing surface current patterns

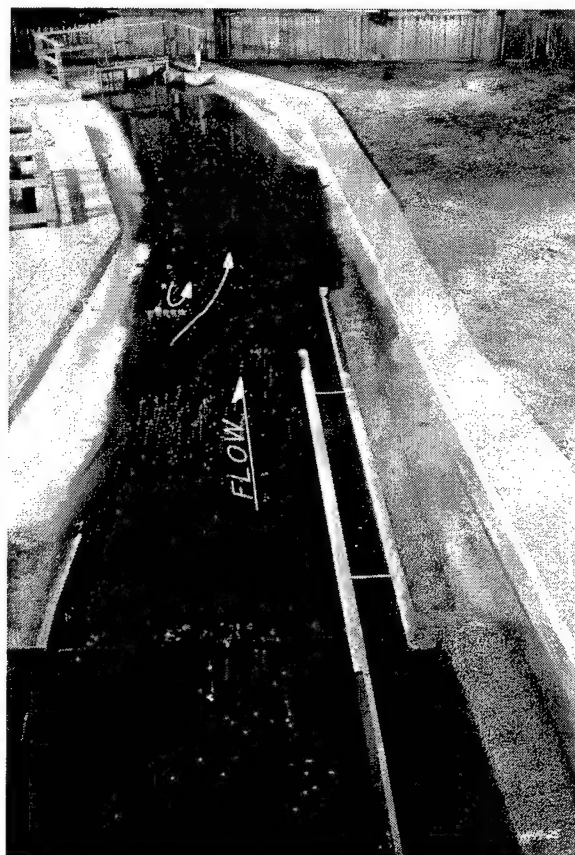




Photo 19. Plan B, looking upstream, showing path of downbound tow approaching lock



Photo 20. Plan B, looking upstream, showing path of upbound tow leaving lock



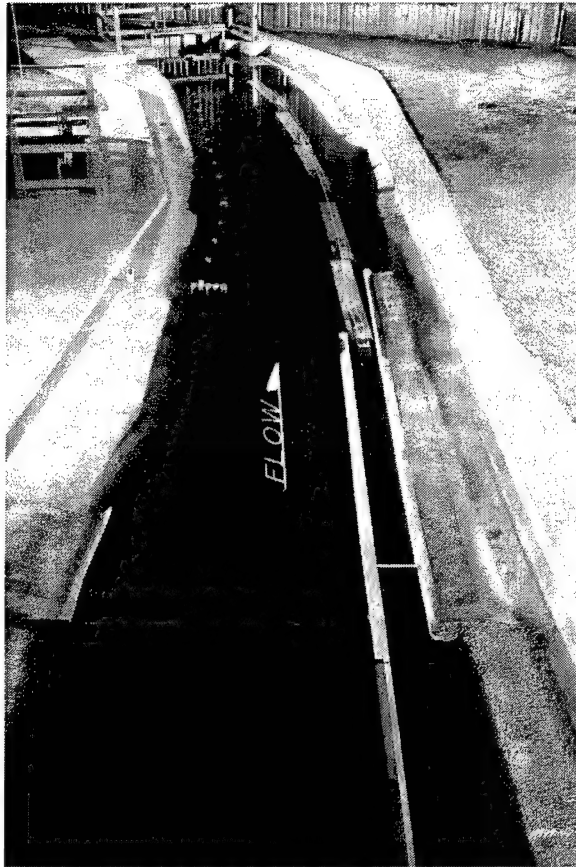


Photo 21. Plan B, looking downstream;  
discharge of 107,500 cfs; showing path of  
downbound tow leaving lock

Photo 22. Plan B, looking downstream;  
discharge of 107,500 cfs; showing path of  
upbound tow approaching lock

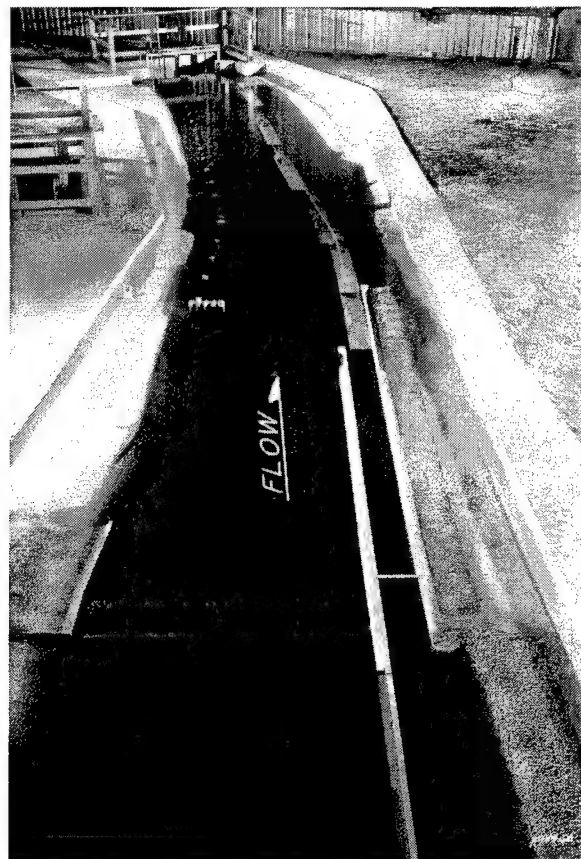






Photo 23. Plan B modified, looking upstream;  
discharge of 51,800 cfs; confetti showing  
surface current patterns

Photo 24. Plan B modified, looking upstream;  
discharge of 107,500 cfs; confetti showing  
current patterns

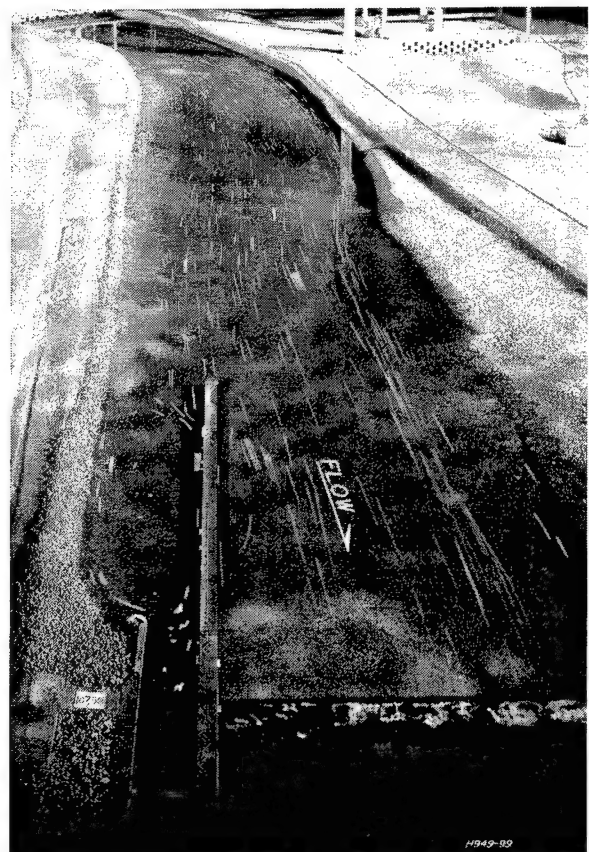
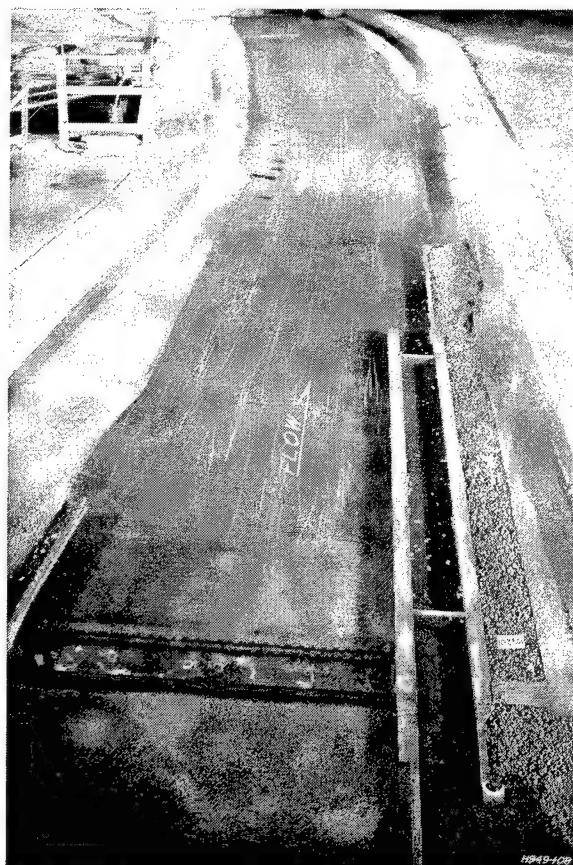




Photo 25. Plan B modified, looking down-stream; discharge of 51,800 cfs; confetti showing surface current patterns

Photo 26. Plan B modified, looking down-stream; discharge of 107,500 cfs; confetti showing surface current patterns



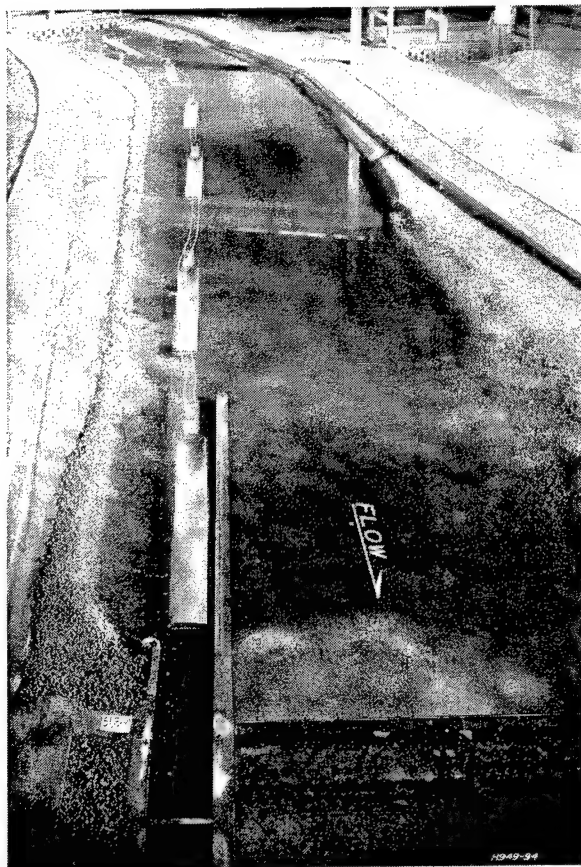


Photo 27. Plan B modified, looking upstream; discharge of 51,800 cfs; showing path of down-bound tow approaching lock

Photo 28. Plan B modified, looking upstream; discharge of 73,000 cfs; showing path of down-bound tow approaching lock



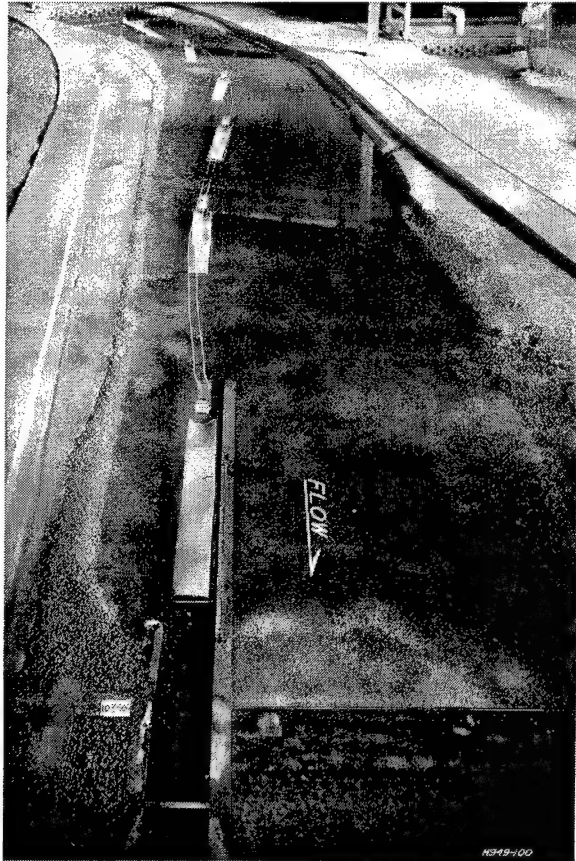


Photo 29. Plan B modified, looking upstream;  
discharge of 107,500 cfs; showing path of  
downbound tow approaching lock

Photo 30. Plan B modified, looking upstream,  
discharge of 51,800 cfs; showing path of  
upbound tow leaving lock





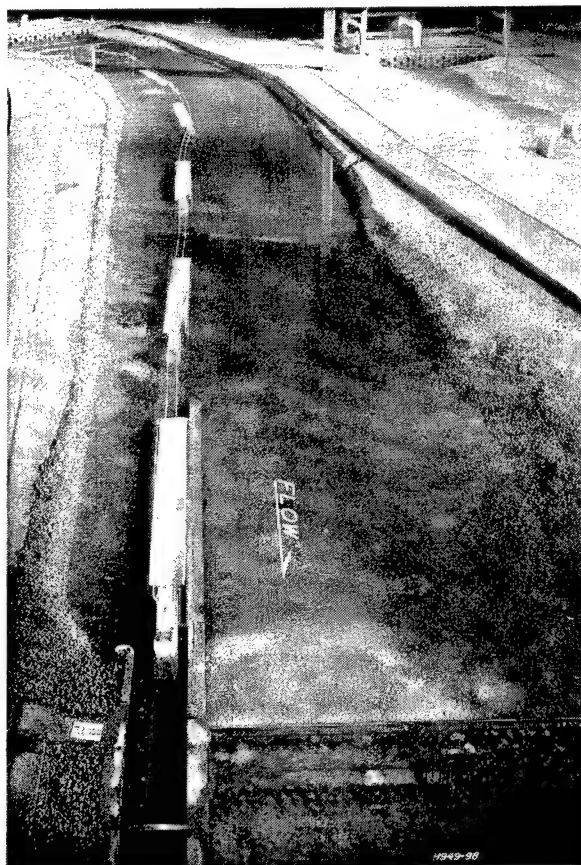


Photo 31. Plan B modified, looking upstream, discharge of 73,000 cfs; showing path of upbound tow leaving lock

Photo 32. Plan B modified, looking upstream; discharge of 107,500 cfs; showing path of upbound tow leaving lock

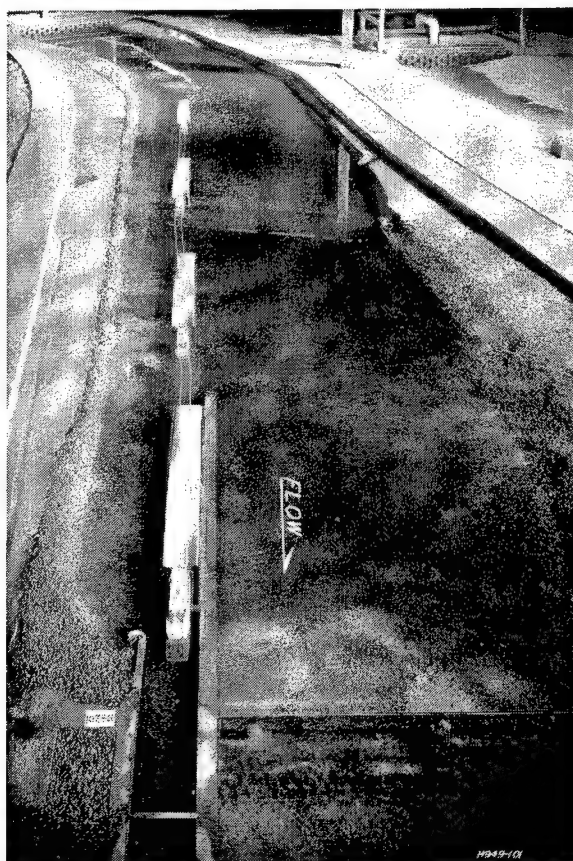




Photo 33. Plan B modified, looking downstream; discharge of 51,800 cfs; showing path of downbound tow leaving lock

Photo 34. Plan B modified, looking downstream; discharge of 73,000 cfs; showing path of downbound tow leaving lock

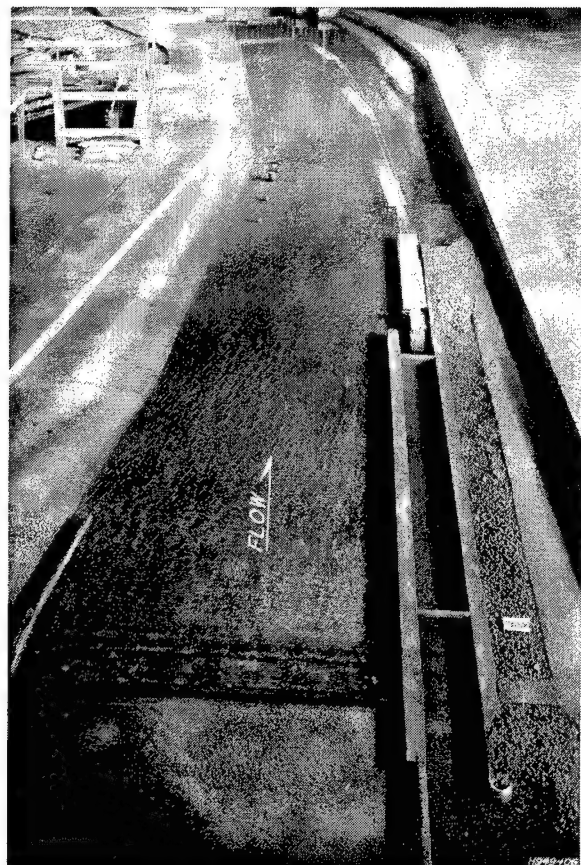




Photo 35. Plan B modified, looking down-stream; discharge of 107,500 cfs; showing path of downbound tow leaving lock

Photo 36. Plan B modified, looking down-stream; discharge of 51,800 cfs; showing path of upbound tow approaching lock





Photo 37. Plan B modified, looking downstream; discharge of 73,000 cfs; showing path of upbound tow approaching lock

Photo 38. Plan B modified, looking downstream; discharge of 107,500 cfs; showing path of upbound tow approaching lock





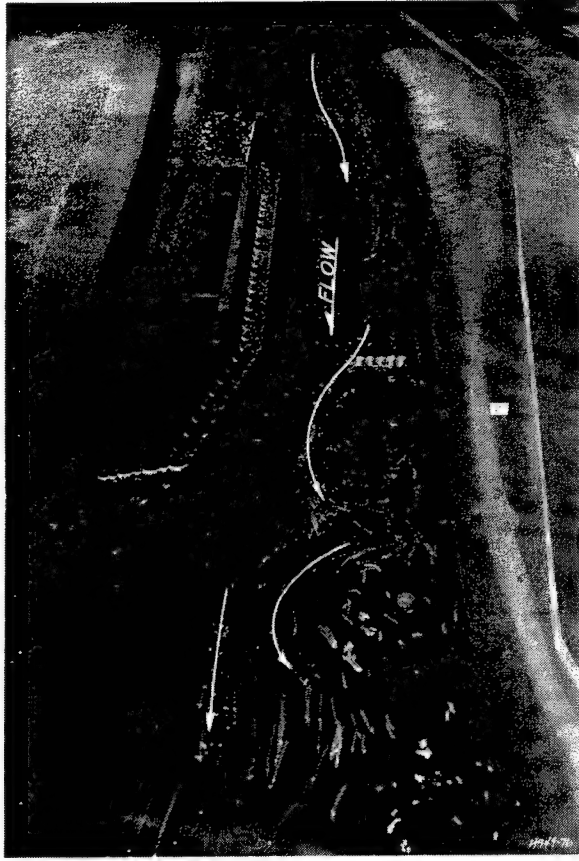
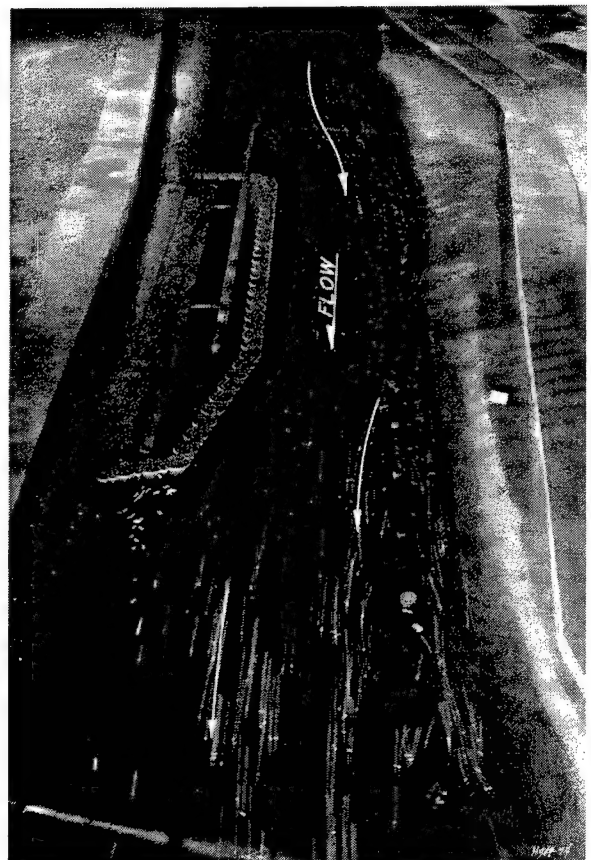


Photo 39. Lock cofferdam with existing icebreaker cells, looking upstream; discharge of 107,500 cfs; confetti showing current pattern

Photo 40. Lock cofferdam, without icebreaker cells, looking upstream; discharge of 107,500 cfs; confetti showing current patterns



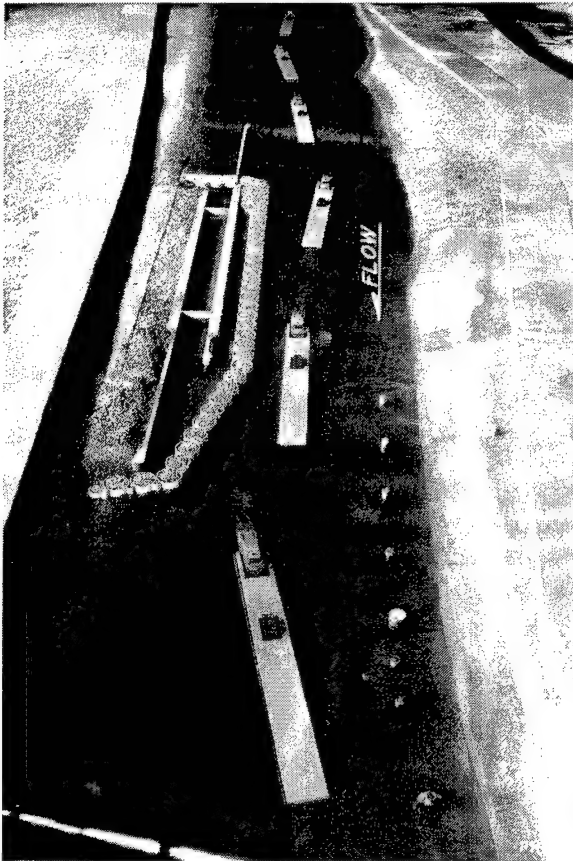


Photo 41. Lock cofferdam, without icebreaker cells, looking upstream; discharge of 51,800 cfs; showing path of downbound tow

Photo 42. Lock cofferdam, without icebreaker cells, looking upstream; discharge of 107,500 cfs; showing path of downbound tow



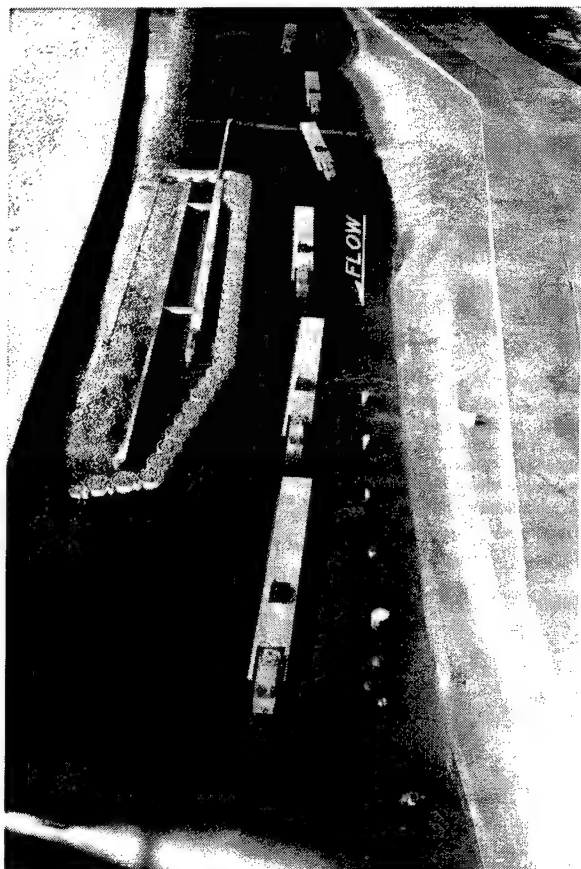


Photo 43. Lock cofferdam, without icebreaker cells, looking upstream; discharge of 51,800 cfs; showing path of upbound tow

Photo 44. Lock cofferdam, without icebreaker cells, looking upstream; discharge of 107,500 cfs; showing path of upbound tow



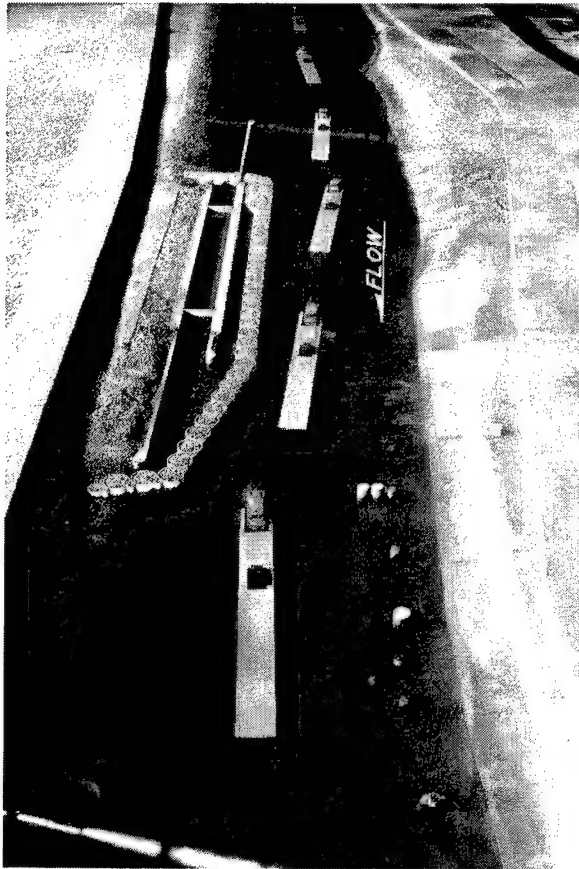
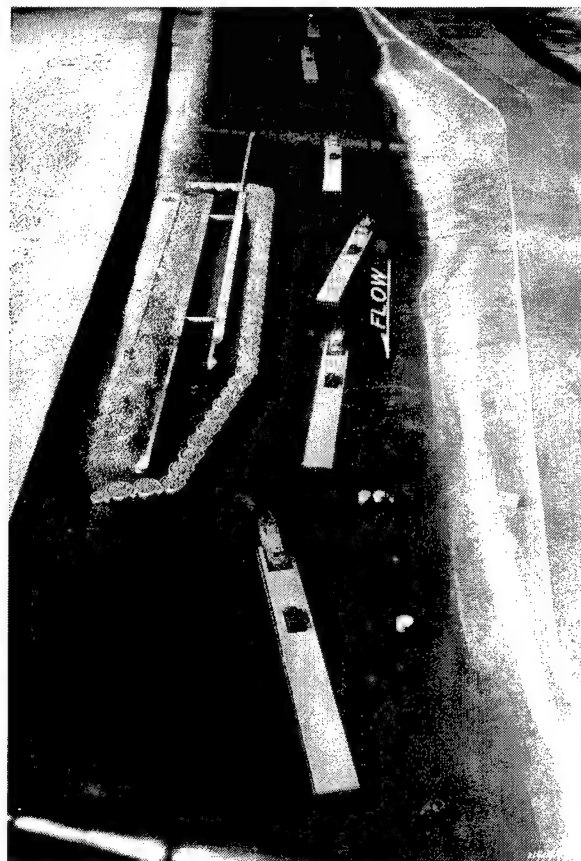


Photo 45. Lock cofferdam, with new icebreaker cells, looking upstream; discharge of 51,800 cfs; showing path of downbound tow

Photo 46. Lock cofferdam, with new icebreaker cells, looking upstream; discharge of 107,500 cfs; showing path of downbound tow



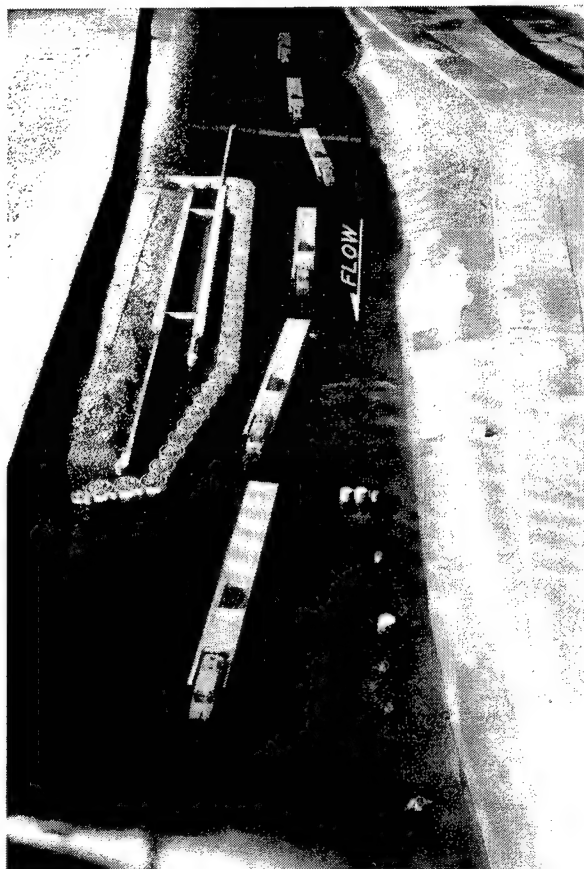
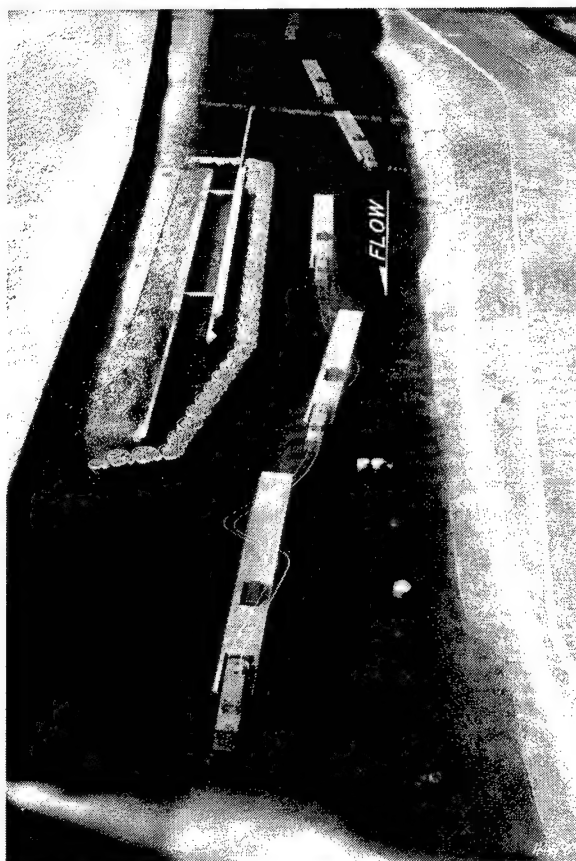


Photo 47. Lock cofferdam, with new icebreaker cells, looking upstream; discharge of 51,800 cfs; showing path of upbound tow

Photo 48. Lock cofferdam, with new icebreaker cells, looking upstream; discharge of 107,500 cfs; showing path of upbound tow



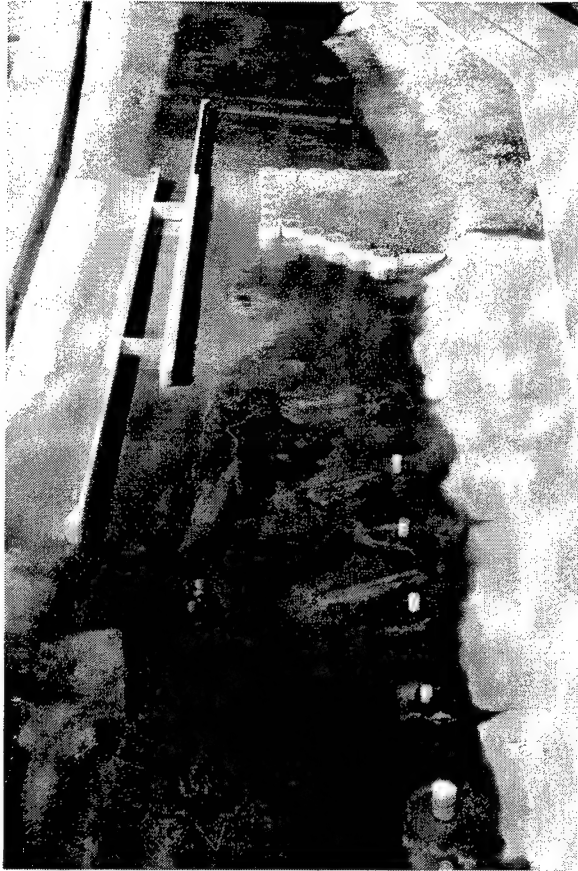


Photo 49. First stage of the dam cofferdam, 175-ft-wide navigation pass modified

Photo 50. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking upstream; discharge of 6,000 cfs; showing path of downbound tow





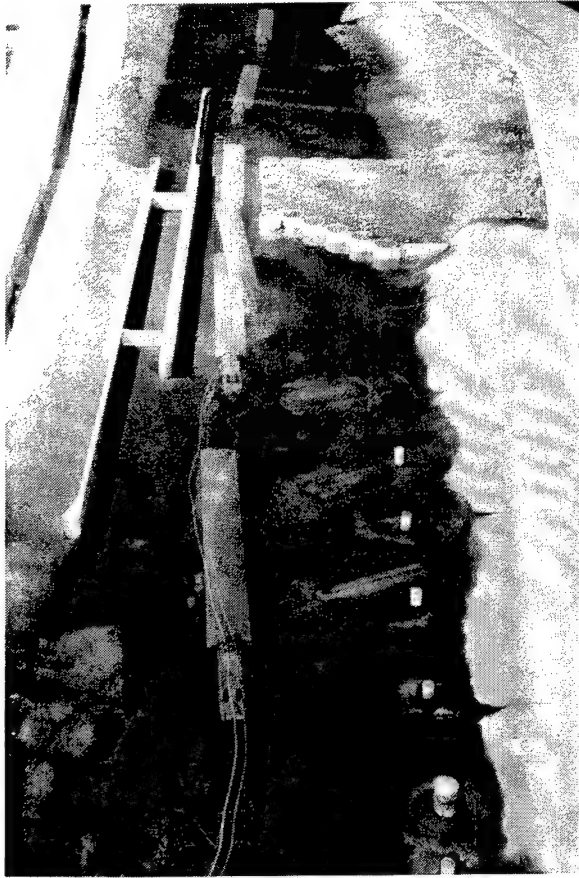


Photo 51. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking upstream; discharge of 6,000 cfs; showing path of upbound tow

Photo 52. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking upstream; discharge of 12,000 cfs; showing path of downbound tow

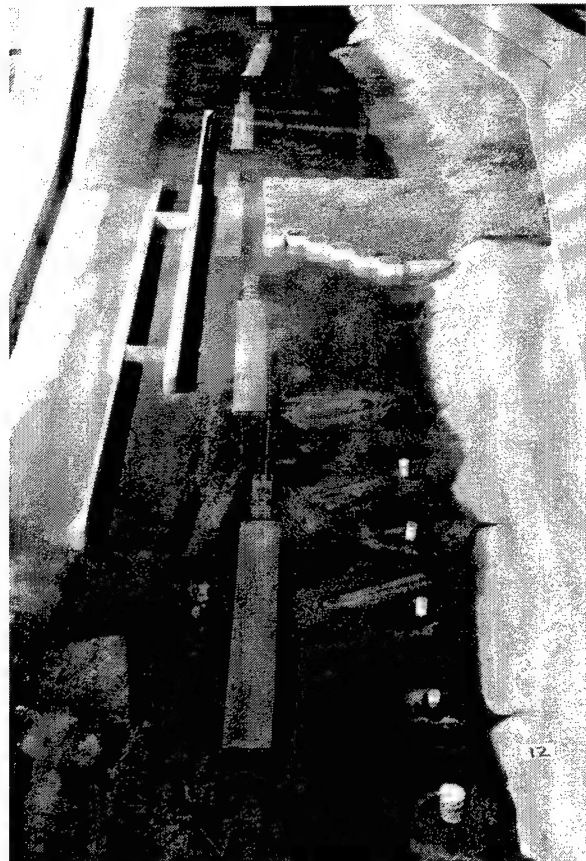




Photo 53. First stage of the dam cofferdam, 172-ft-wide navigation pass modified, looking upstream; discharge of 12,000 cfs; showing path of upbound tow navigating through the pass



Photo 54. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking upstream; discharge of 12,000 cfs; showing path of downbound tow approaching lock





Photo 55. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking upstream; discharge of 12,000 cfs; showing path of upbound tow leaving lock

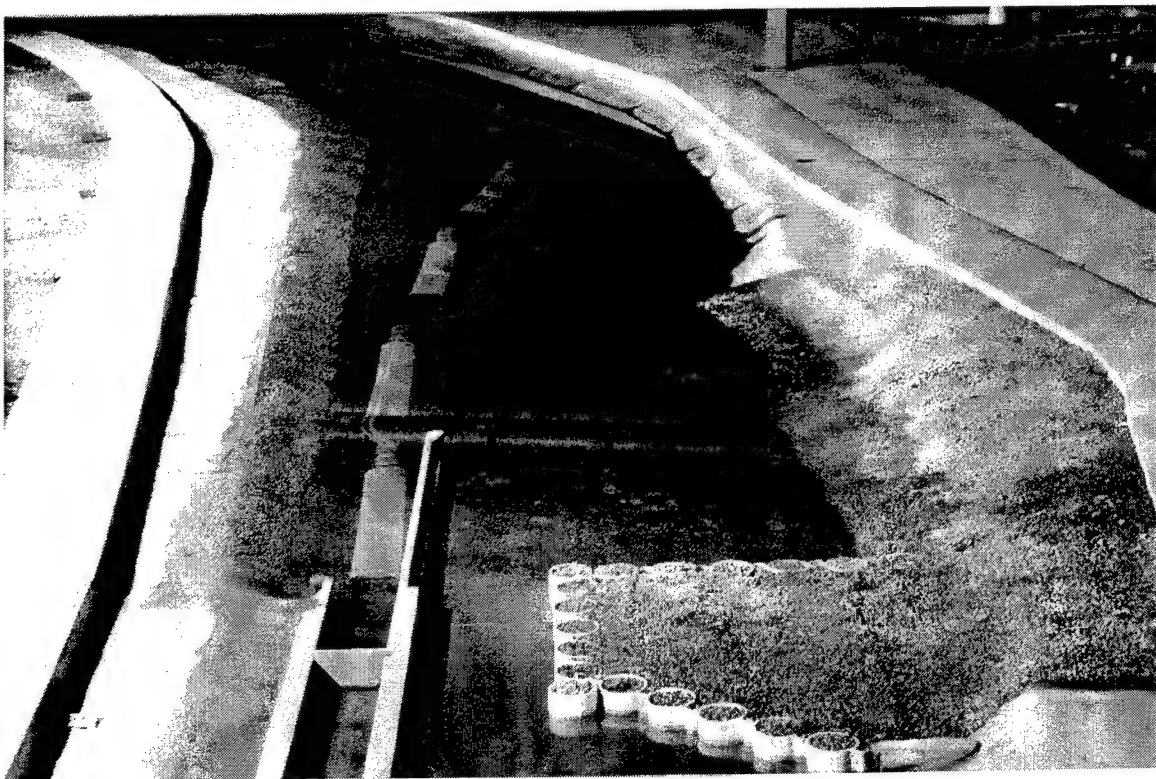


Photo 56. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking upstream; discharge of 25,000 cfs; showing path of downbound tow approaching lock



Photo 57. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking upstream; discharge of 25,000 cfs; showing path of upbound tow leaving lock



Photo 58. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking upstream; discharge of 51,800 cfs; showing path of downbound tow approaching lock

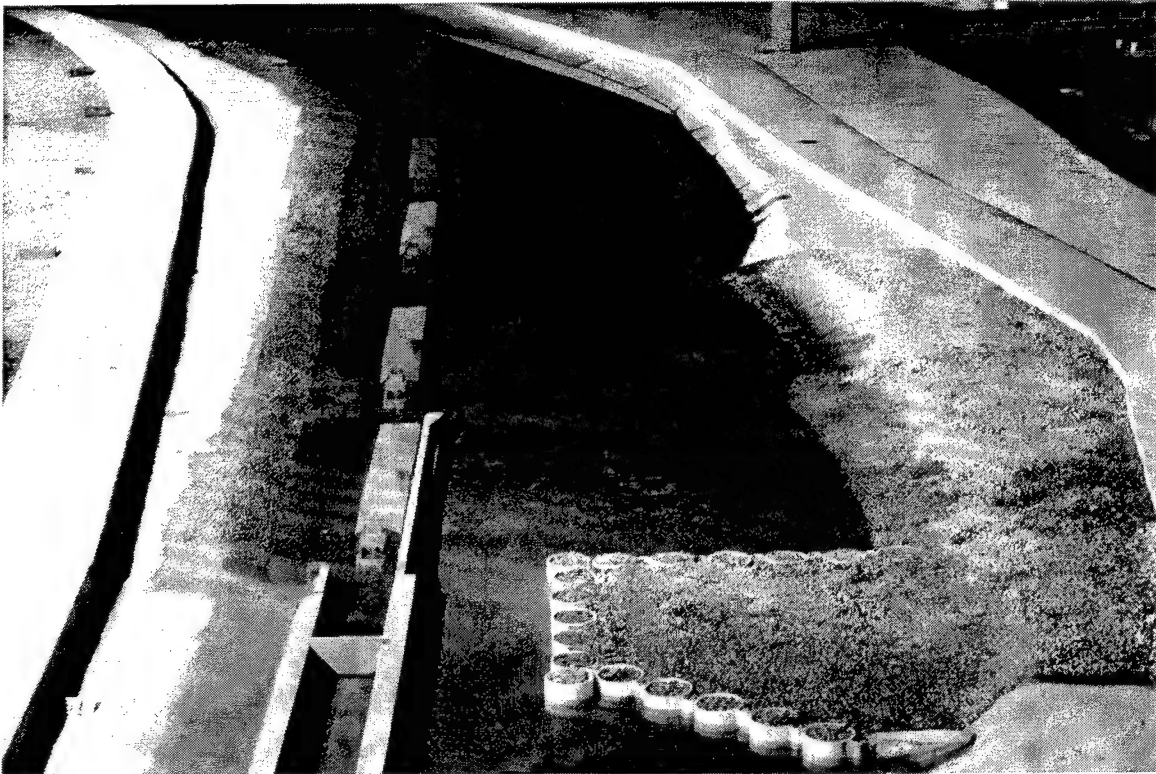


Photo 59. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking upstream; discharge of 51,800 cfs; showing path of upbound tow leaving lock

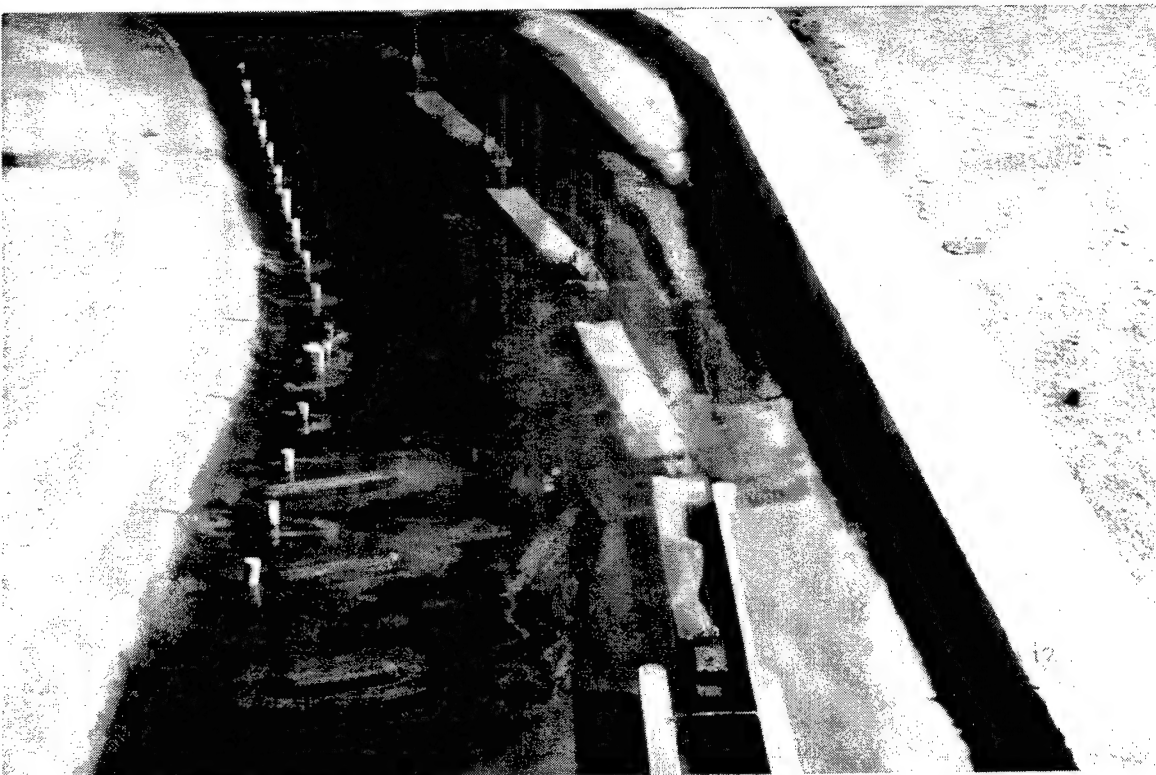


Photo 60. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking downstream; discharge of 12,000 cfs; showing path of downbound tow leaving lock



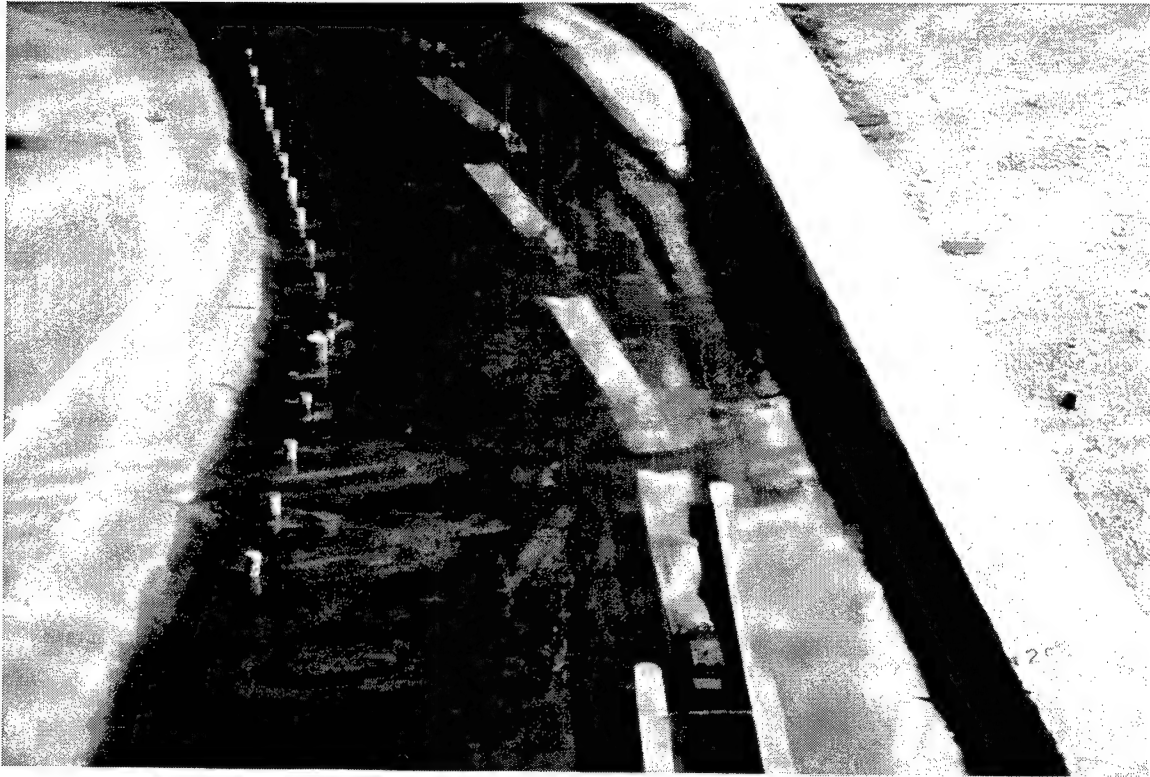


Photo 61. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking downstream; discharge of 25,000 cfs, showing path of downbound tow leaving lock



Photo 62. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking downstream; discharge of 51,800 cfs; showing path of downbound tow leaving lock



Photo 63. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking downstream; discharge of 12,000 cfs; showing path of upbound tow approaching lock

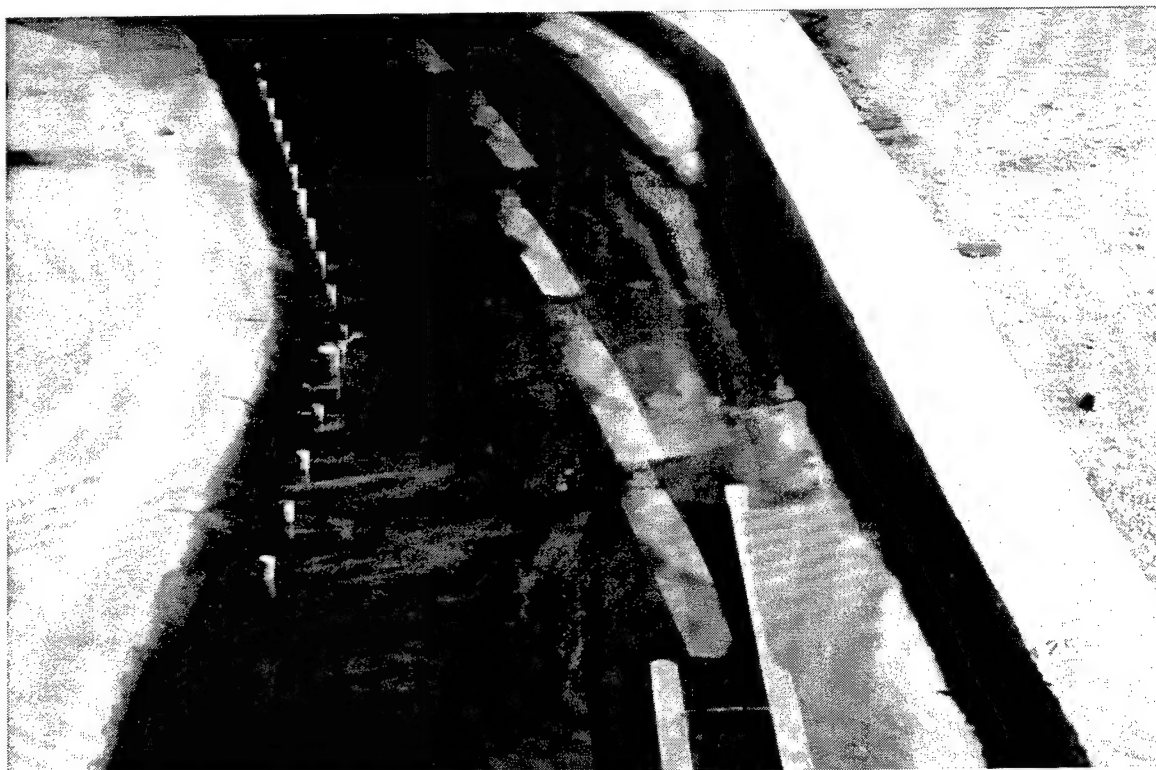
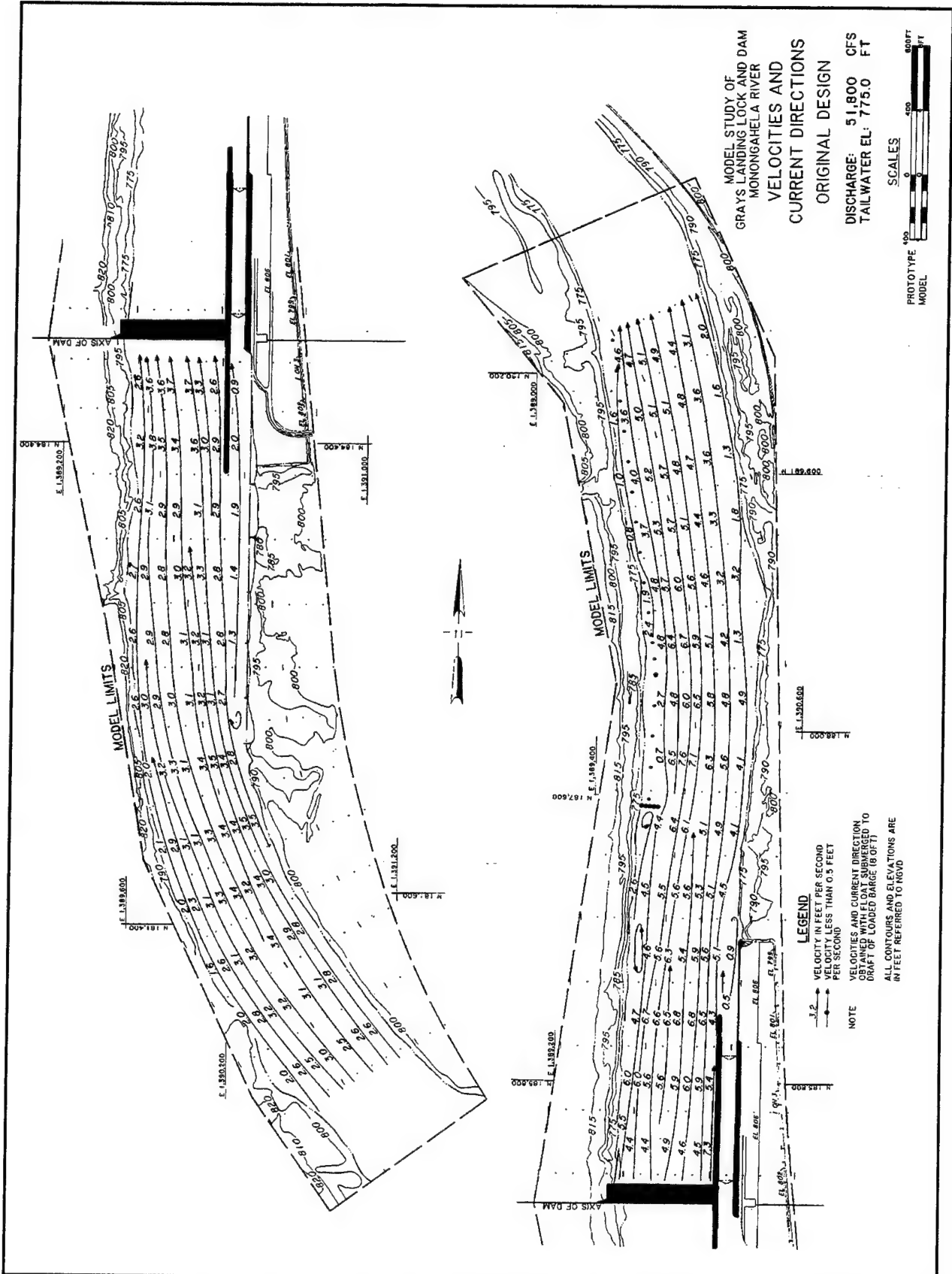


Photo 64. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking downstream; discharge of 25,000 cfs; showing path of upbound tow approaching lock

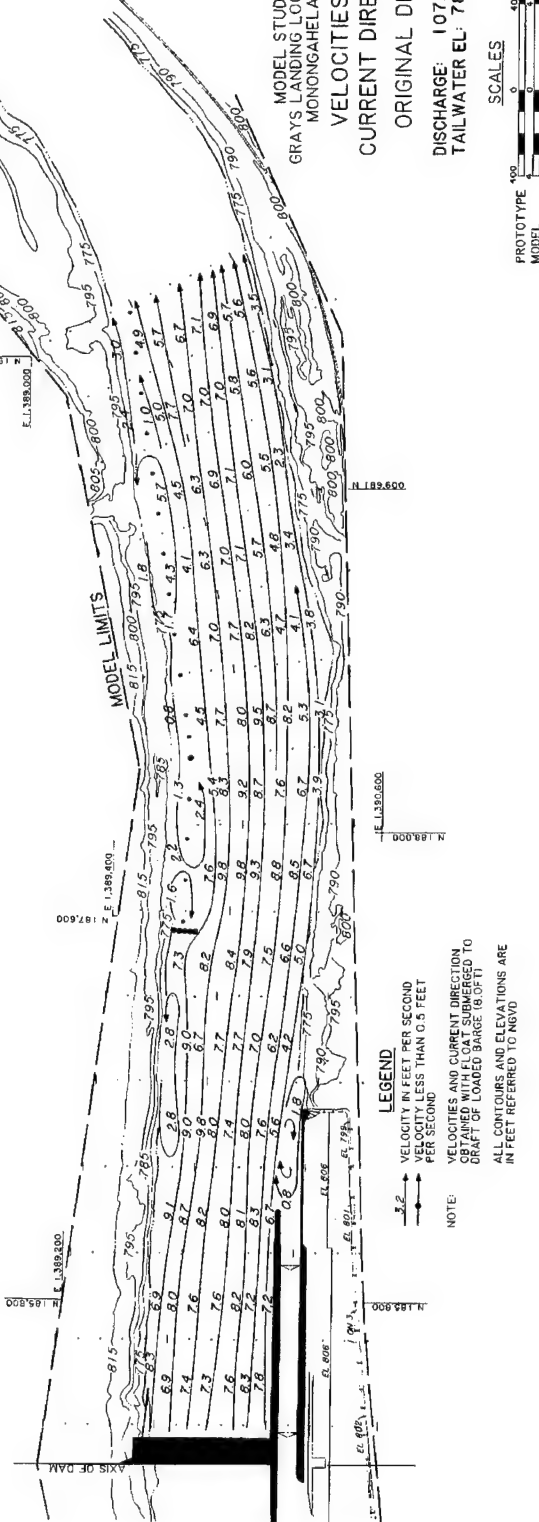
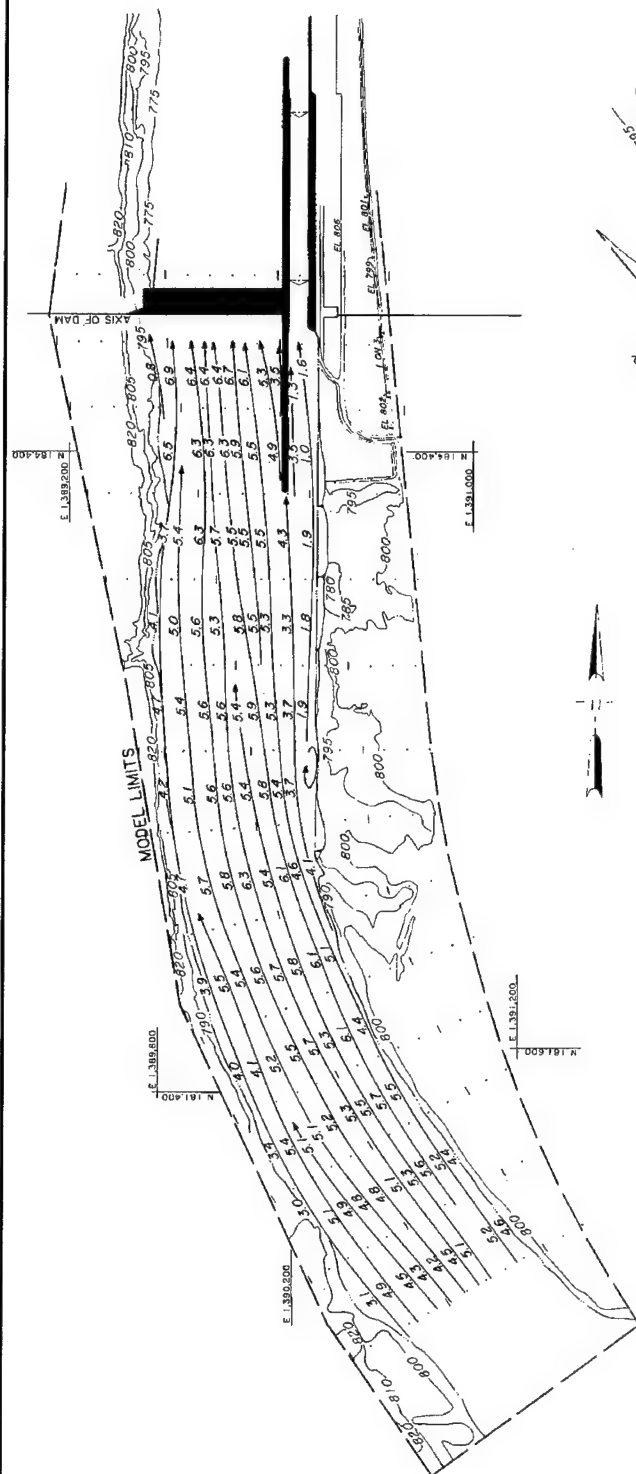


Photo 65. First stage of the dam cofferdam, 175-ft-wide navigation pass modified, looking downstream; discharge of 51,800 cfs; showing path of upbound tow approaching lock









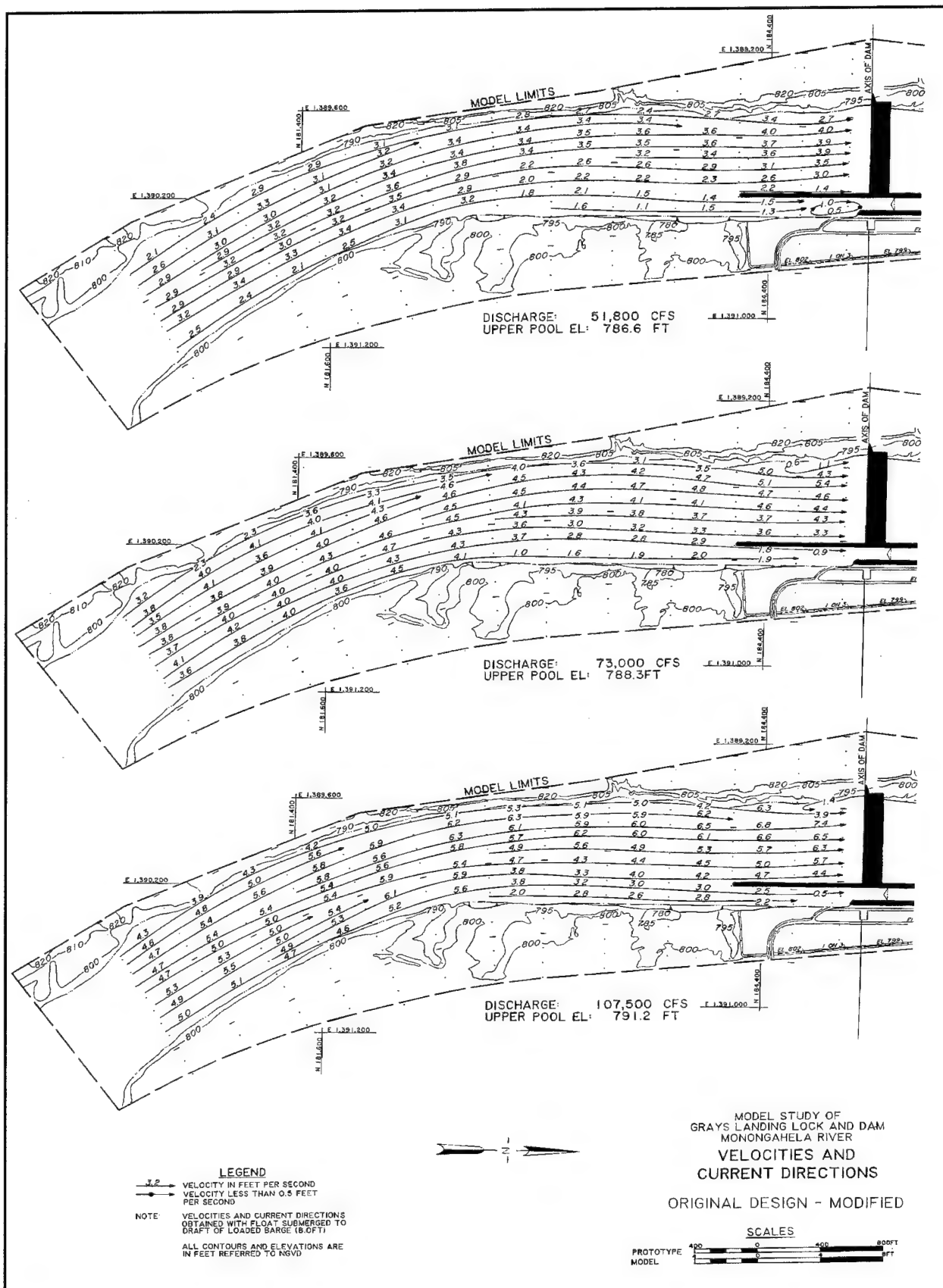
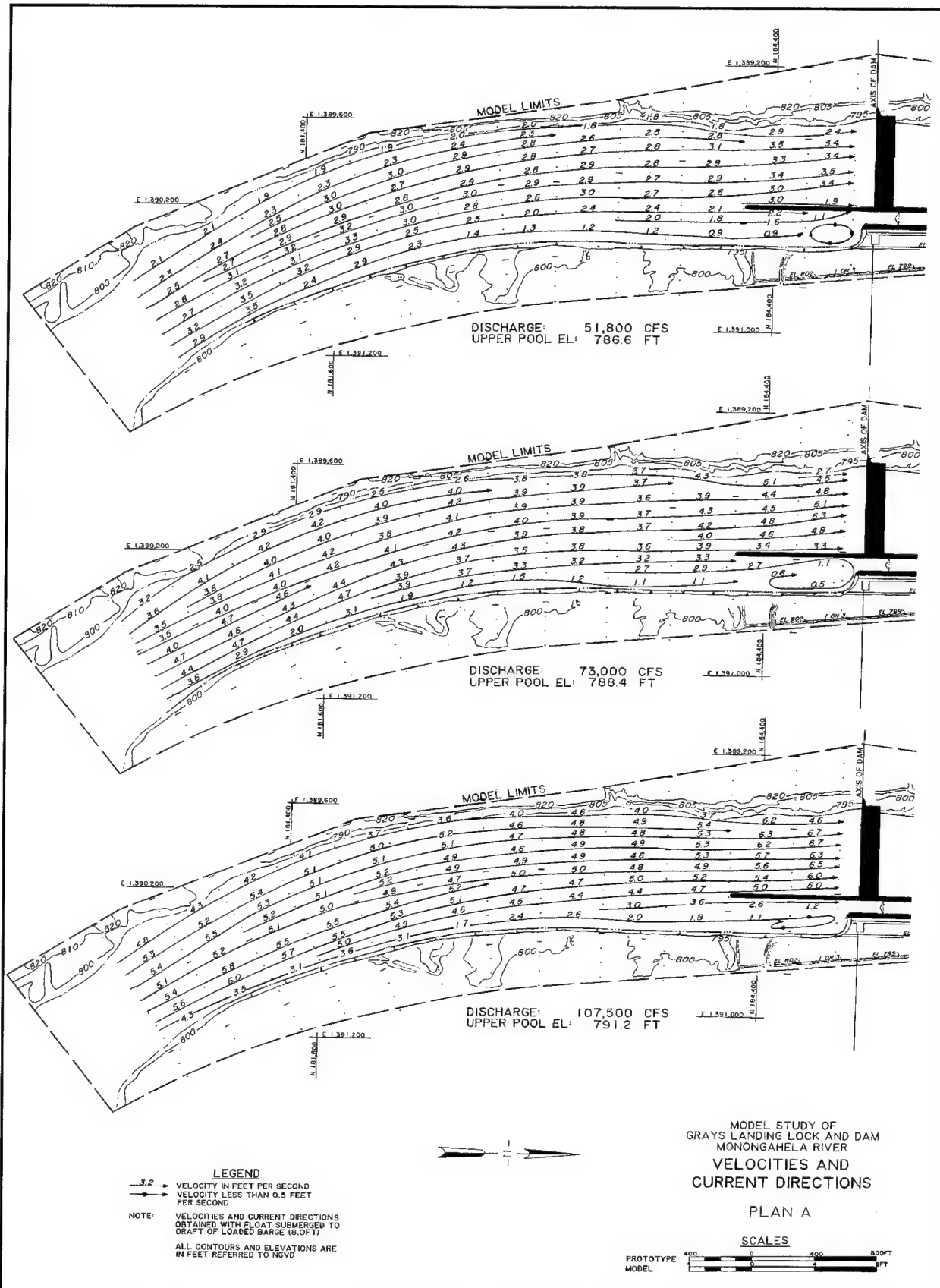


Plate 4



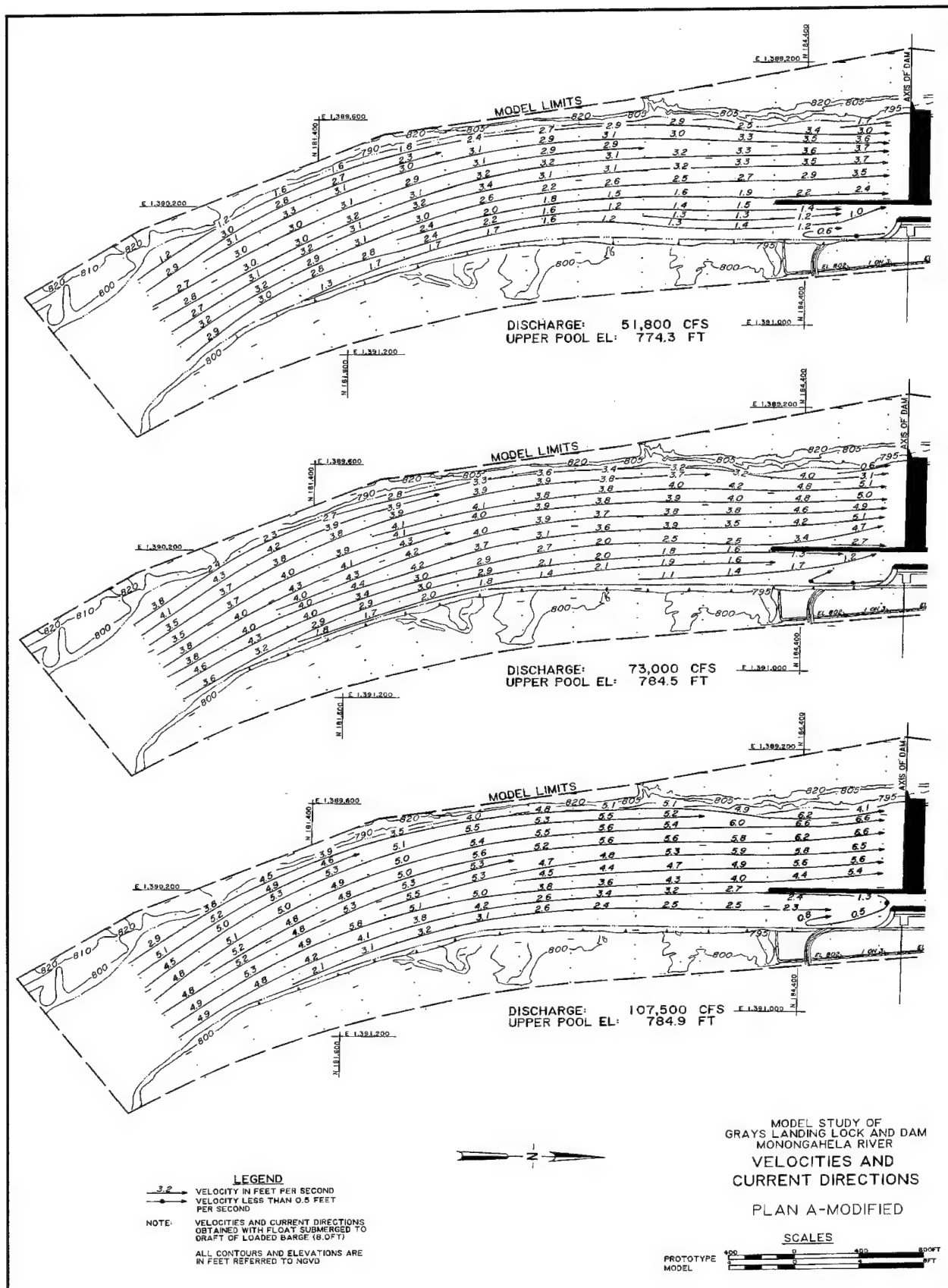
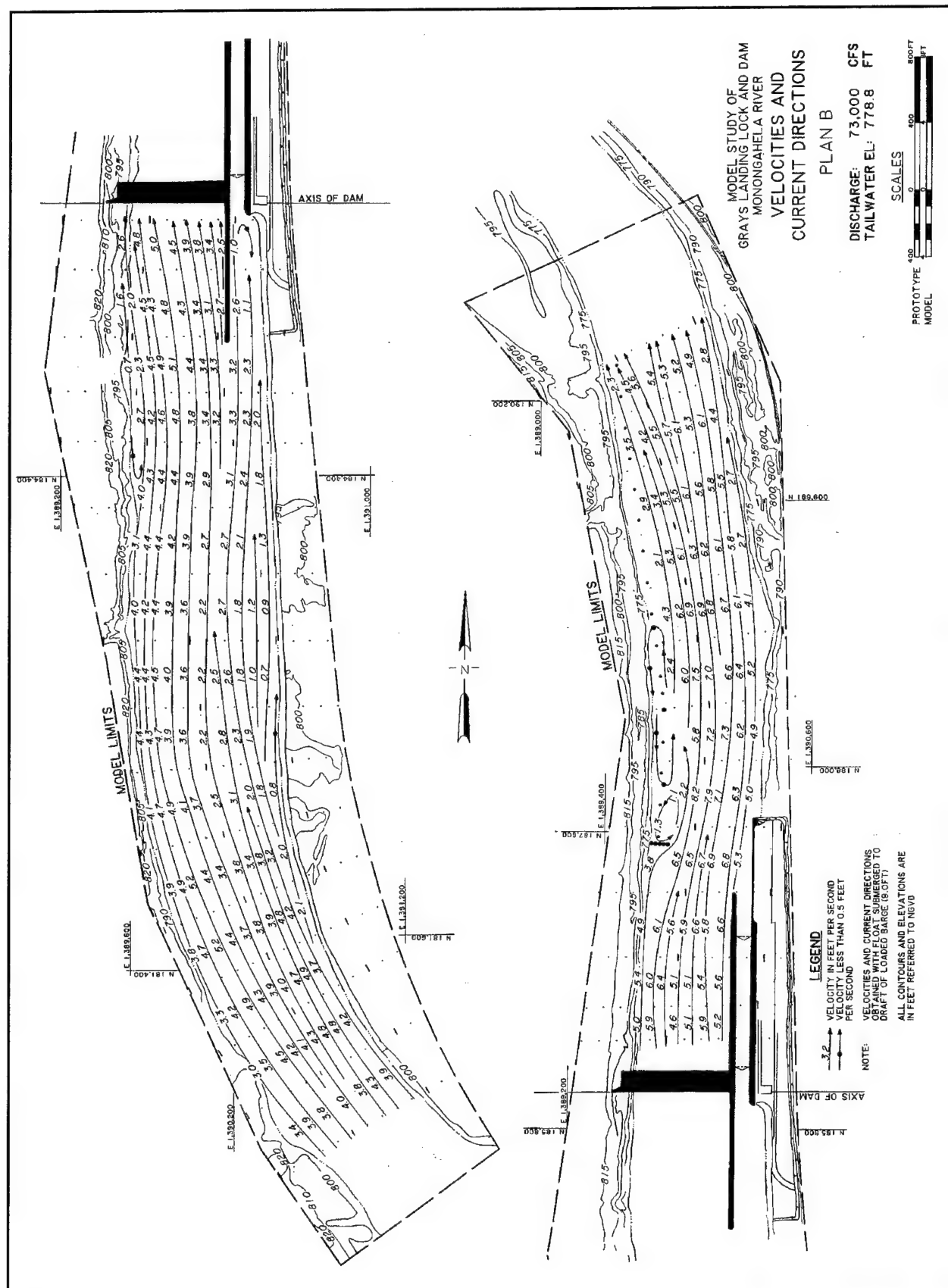


Plate 6



Plate 8



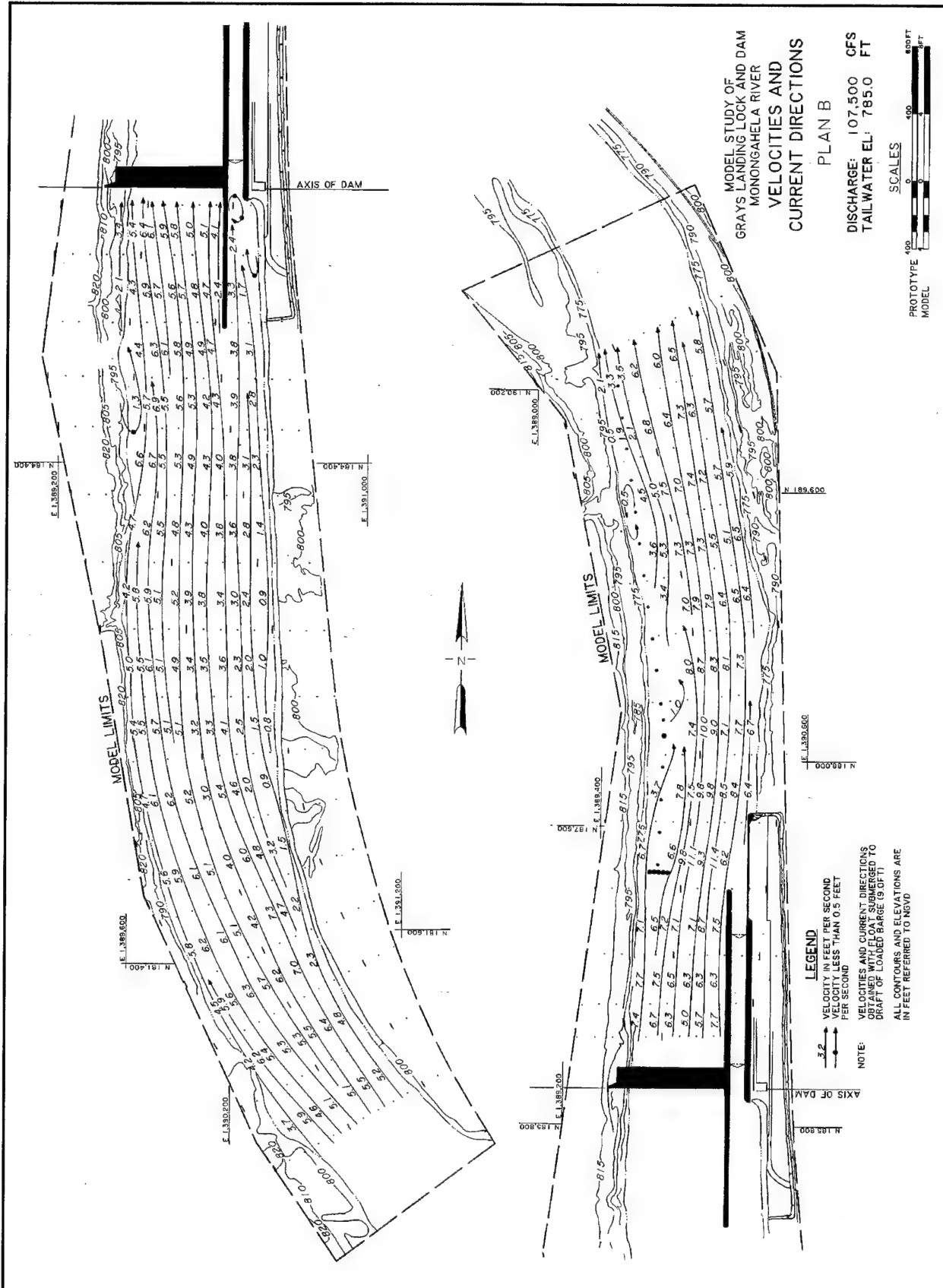
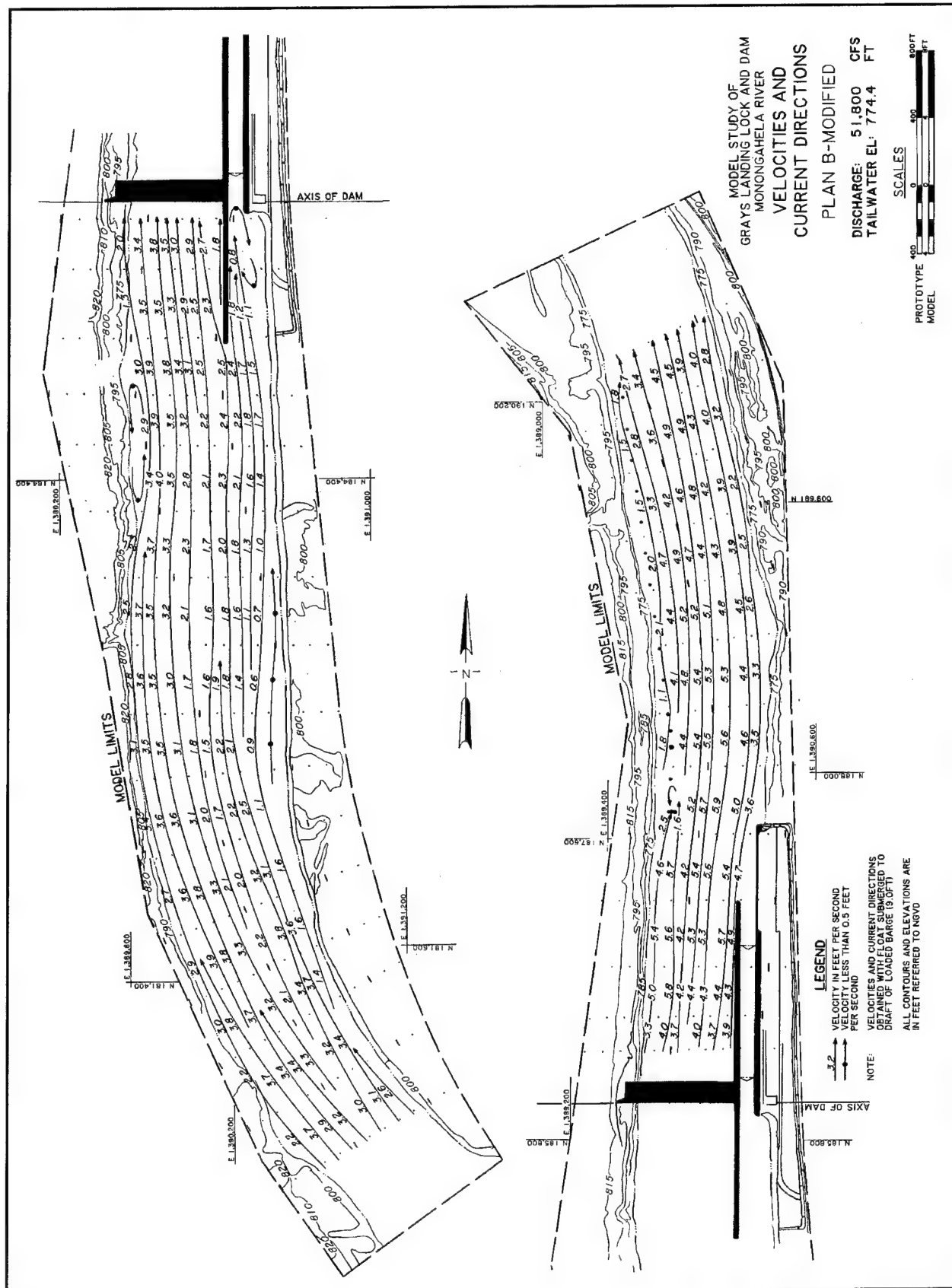
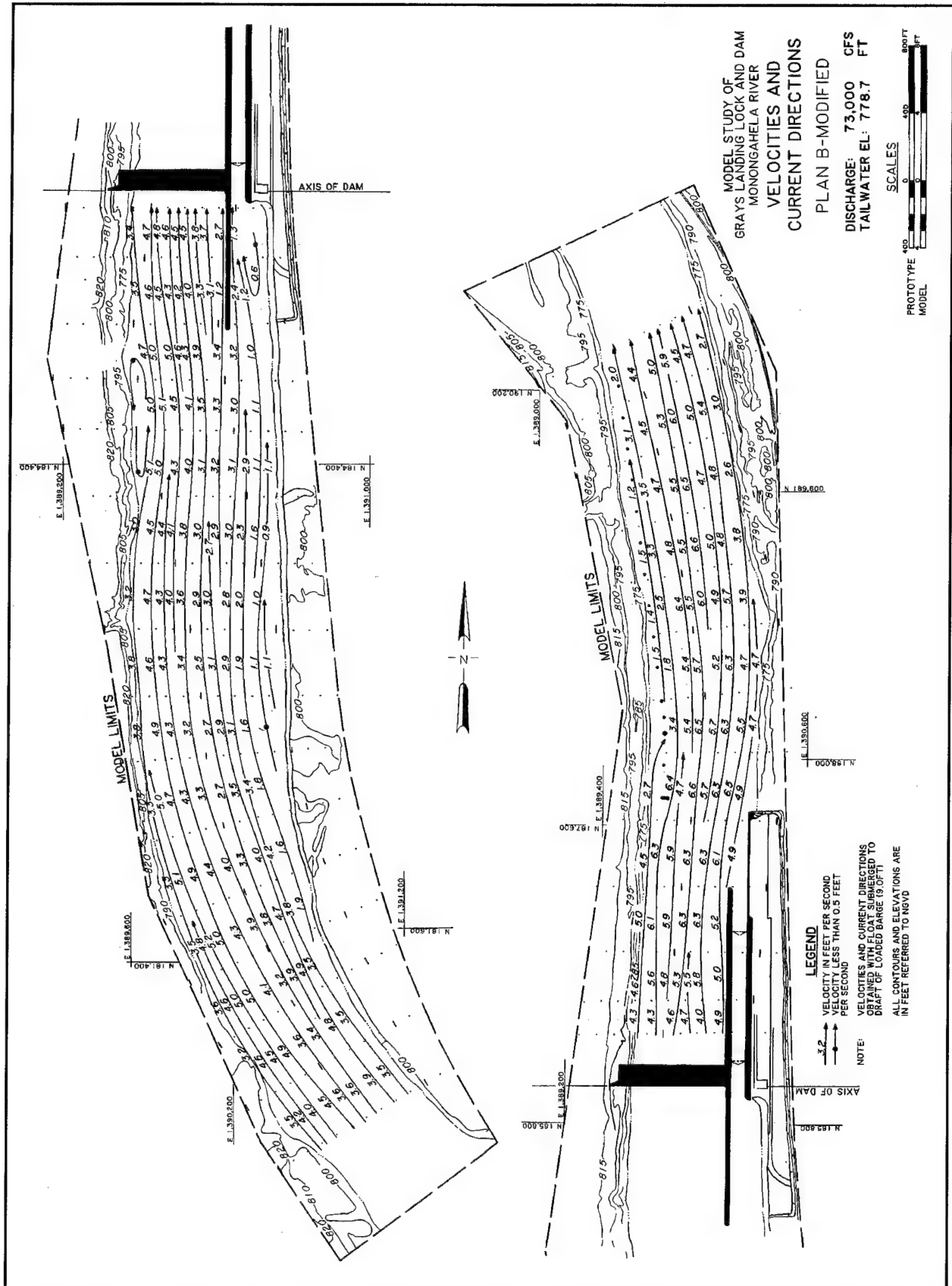


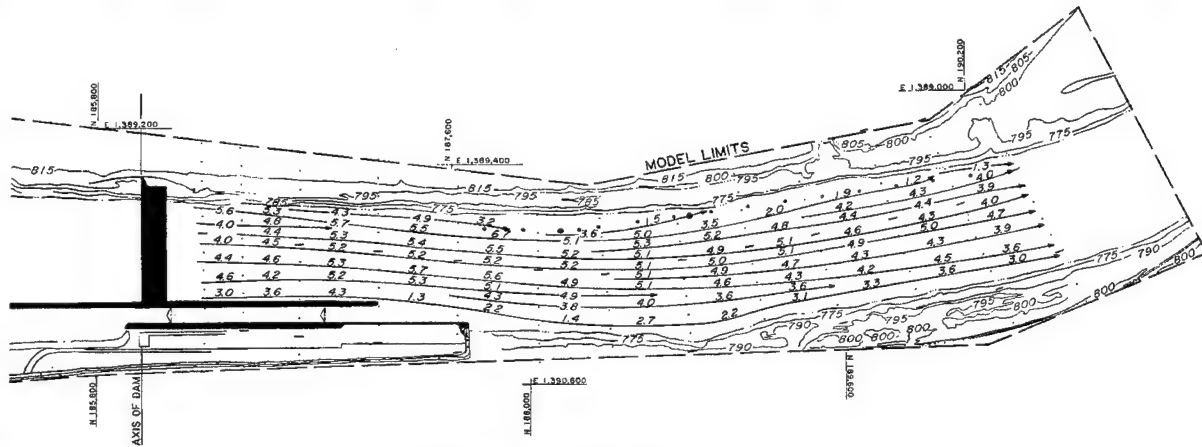
Plate 10



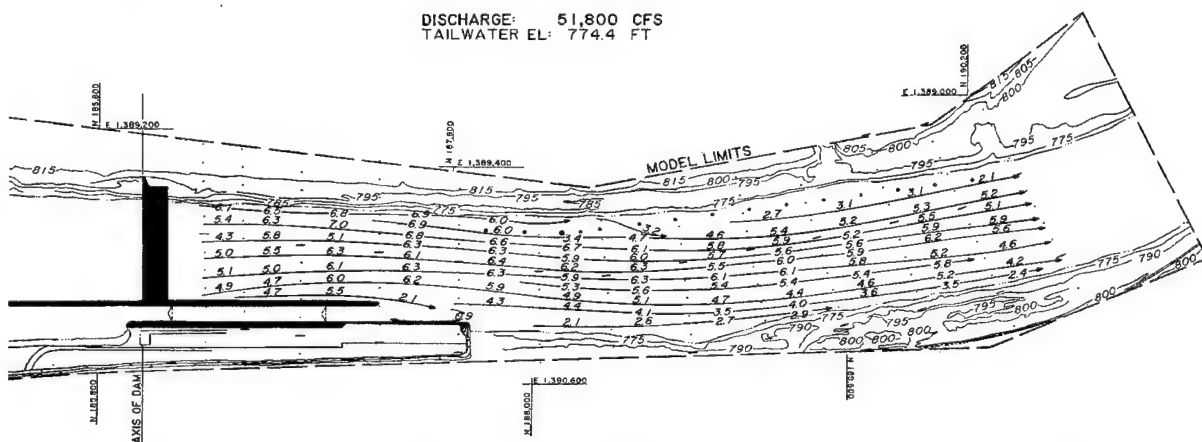




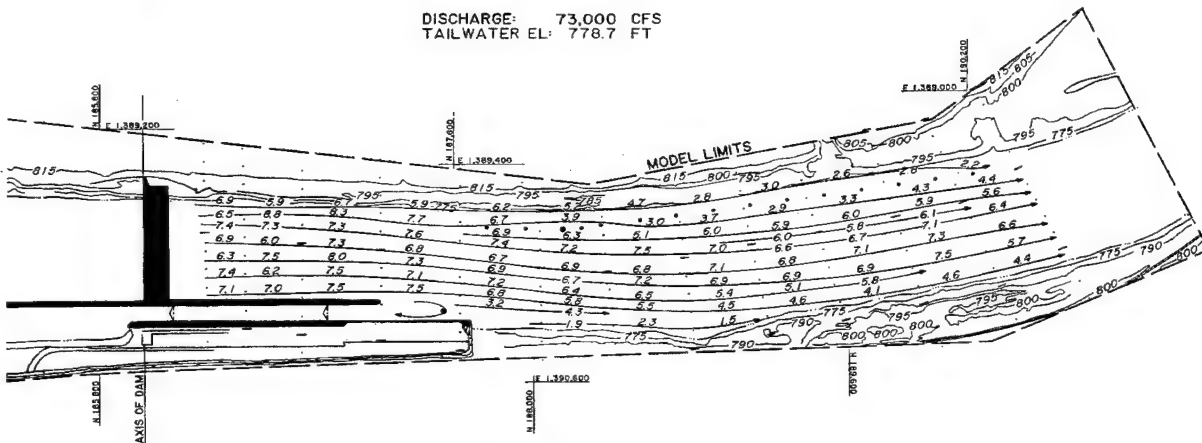




DISCHARGE: 51,800 CFS  
TAILWATER EL: 774.4 FT



DISCHARGE: 73,000 CFS  
TAILWATER EL: 778.7 FT



DISCHARGE: 107,500 CFS  
TAILWATER EL: 784.8 FT

**LEGEND**  
 VELOCITY IN FEET PER SECOND  
 VELOCITY LESS THAN 0.5 FEET PER SECOND  
**NOTE:**  
 VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)  
 ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

MODEL STUDY OF  
GRAYS LANDING LOCK AND DAM  
MONONGAHELA RIVER  
**VELOCITIES AND  
CURRENT DIRECTIONS  
PLAN B-MODIFIED  
(ICE BREAKERS OUT)**

**SCALES**  
 PROTOTYPE 0 200 400 600 FT  
 MODEL 0 20 40 60 FT

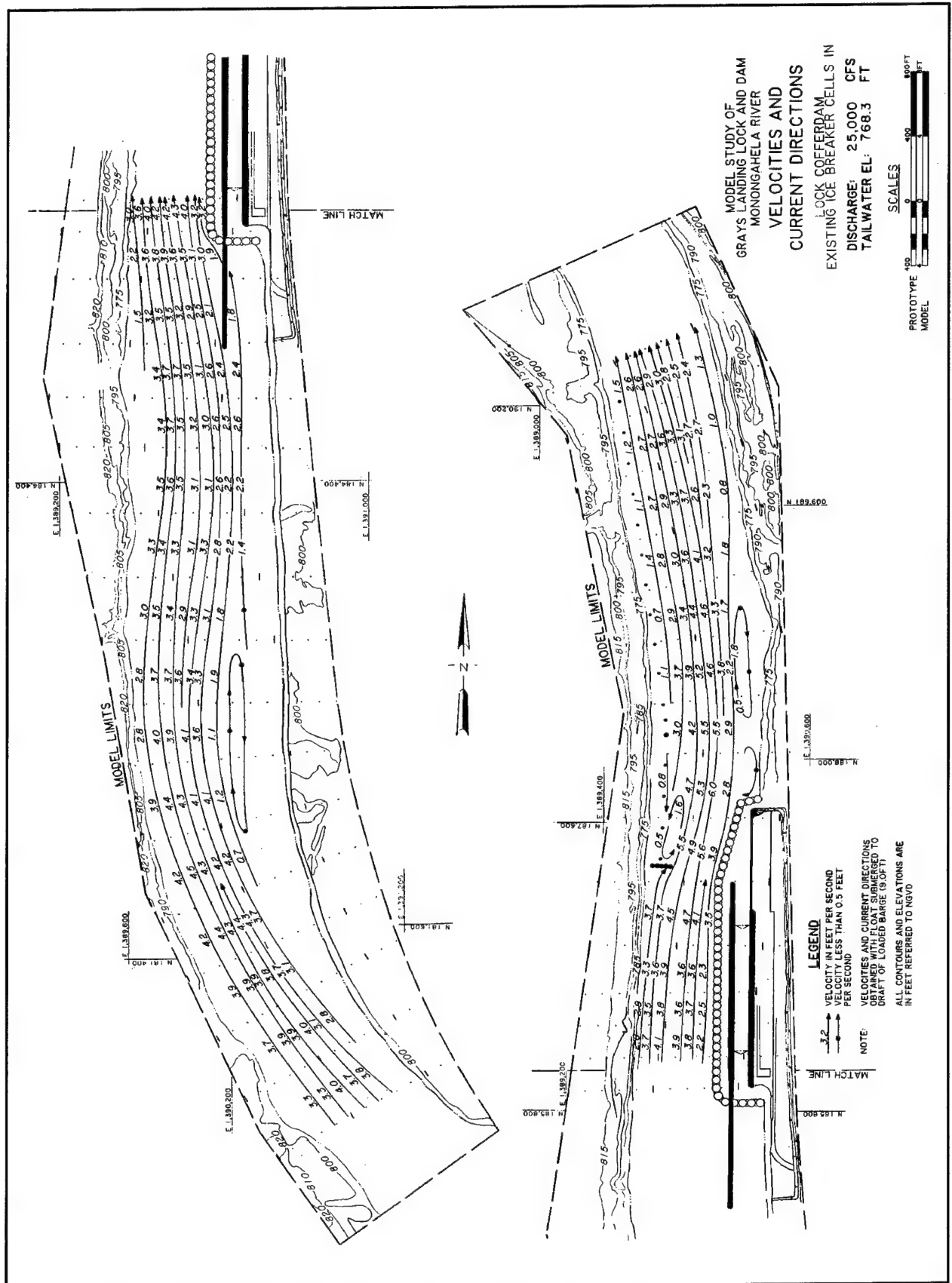
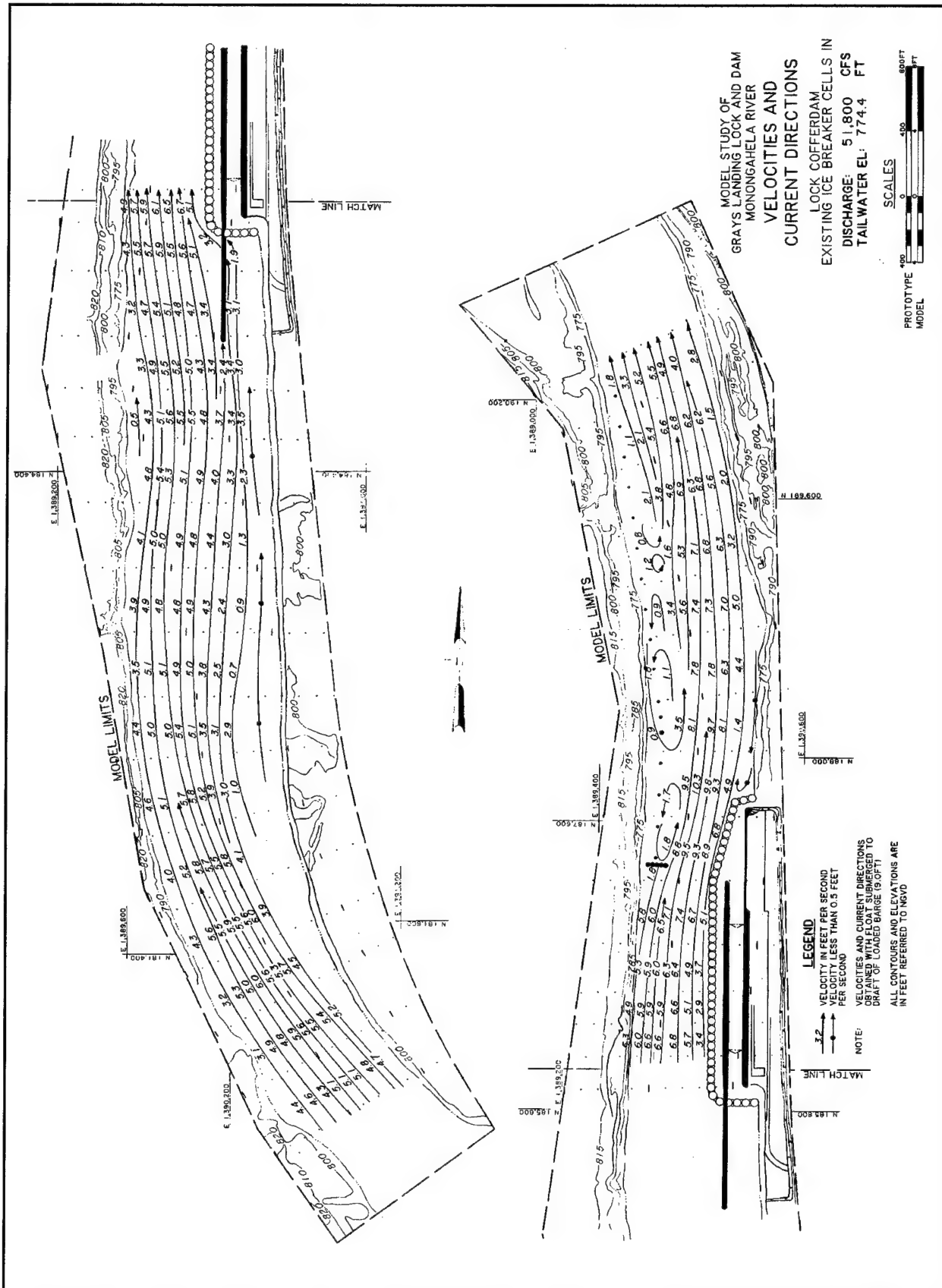


Plate 14



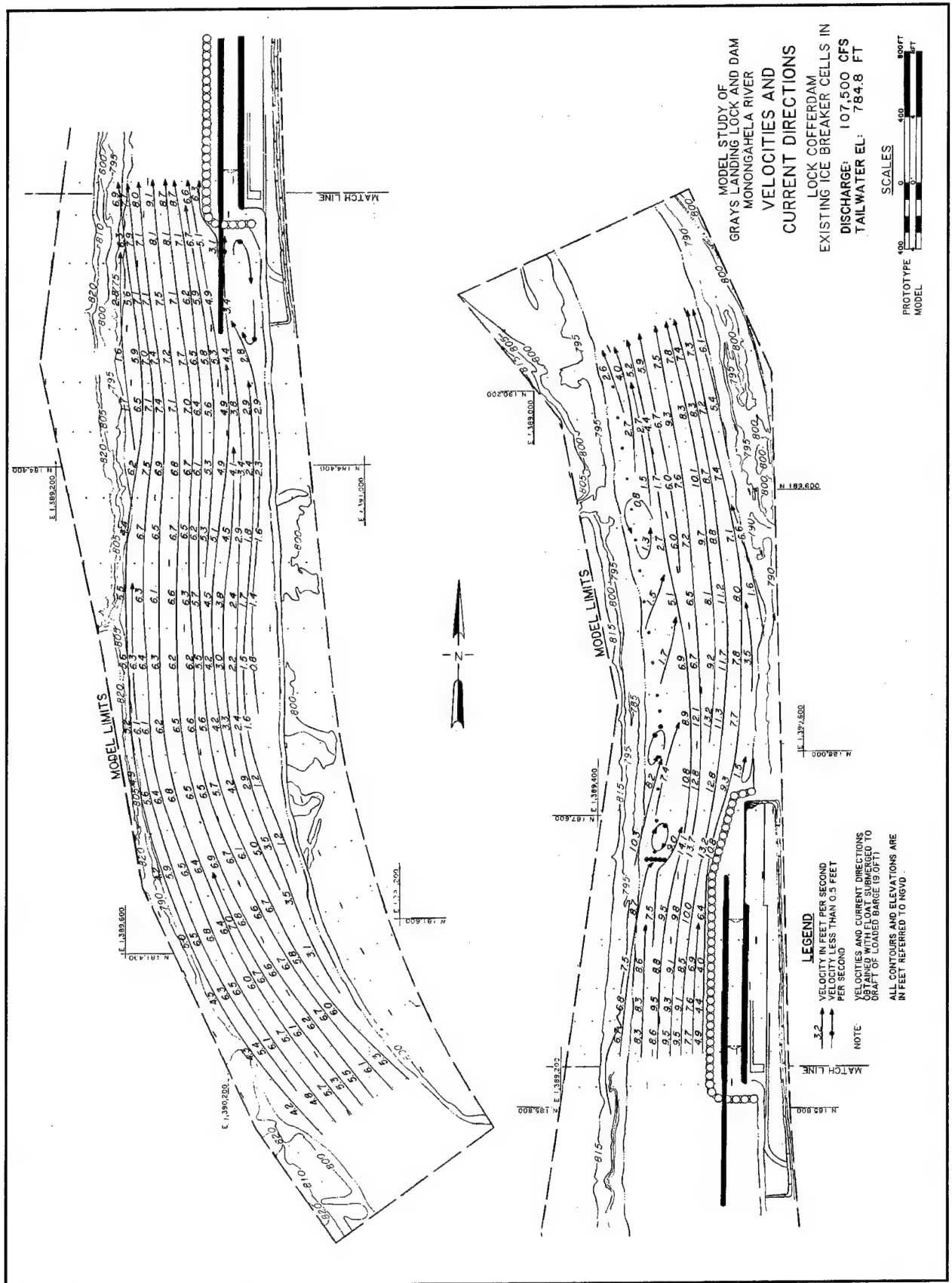
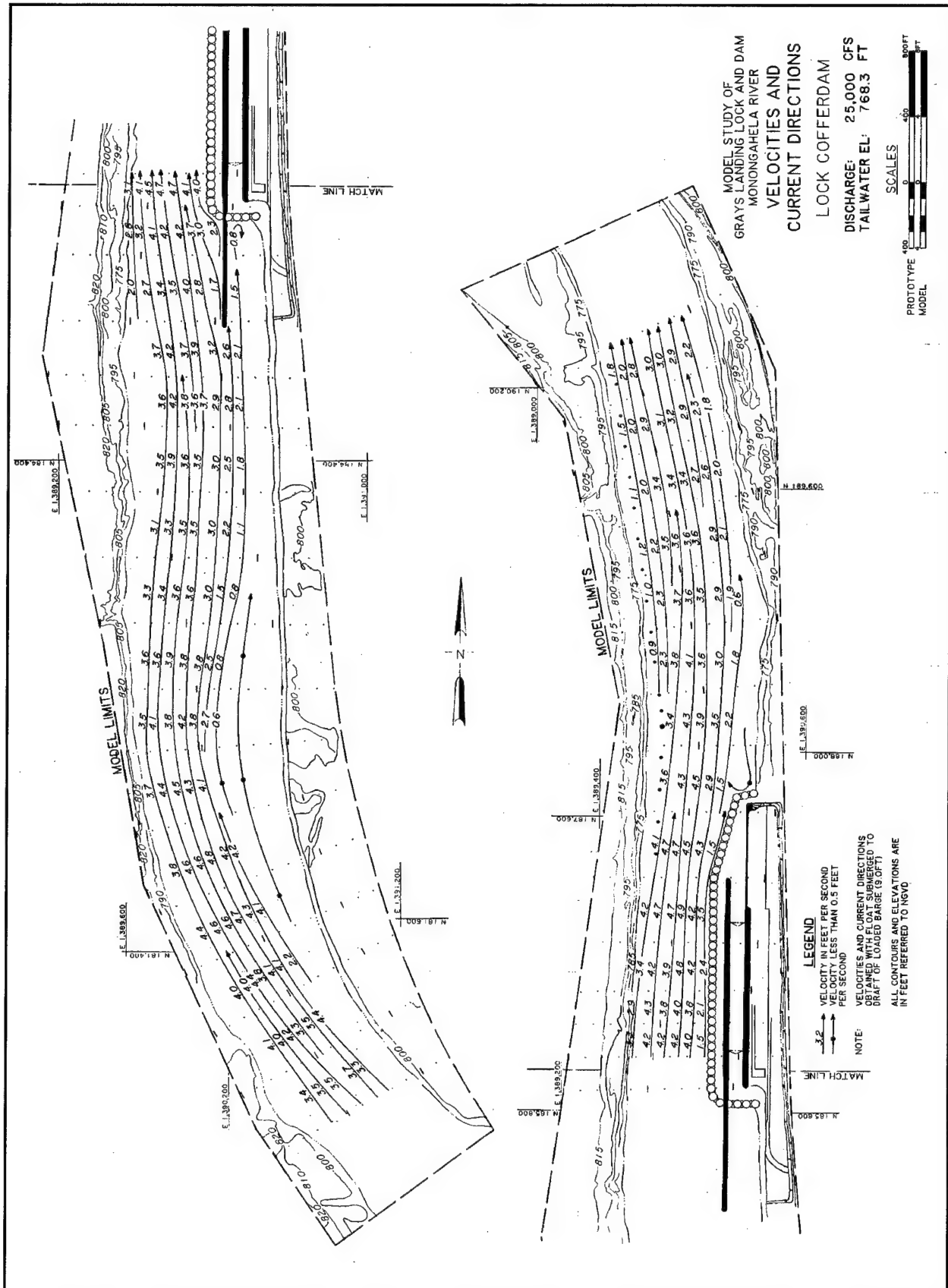


Plate 16



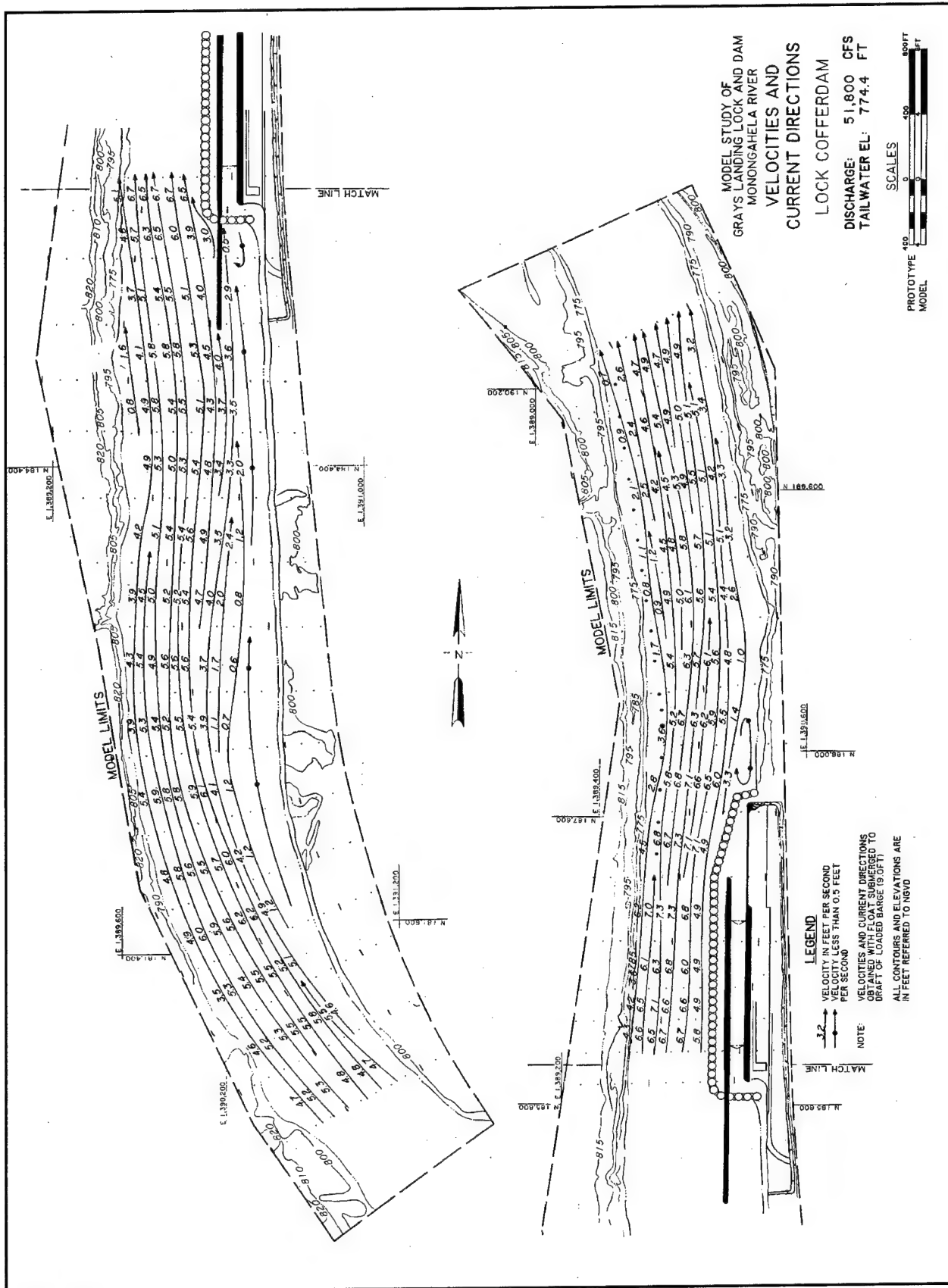
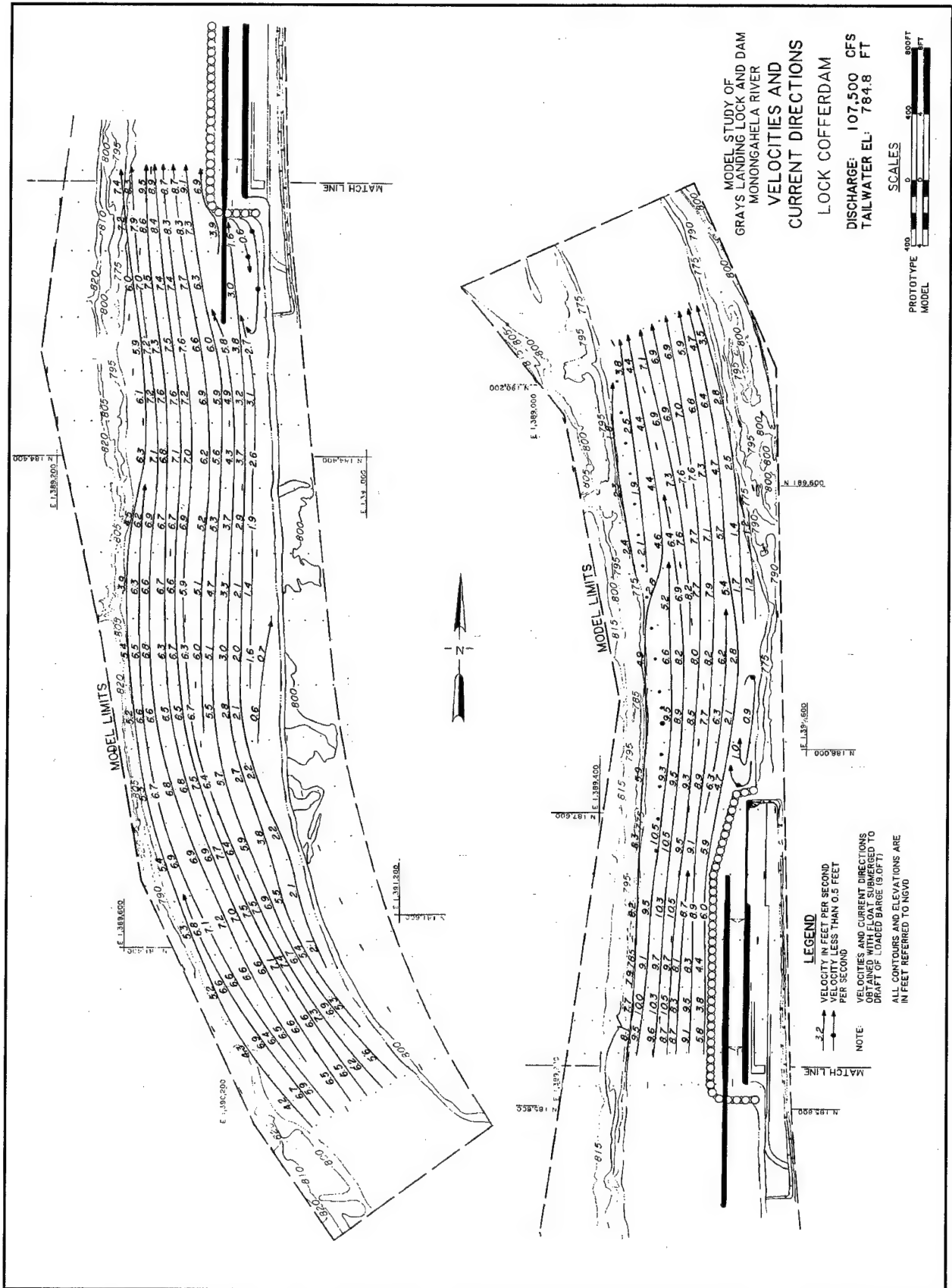
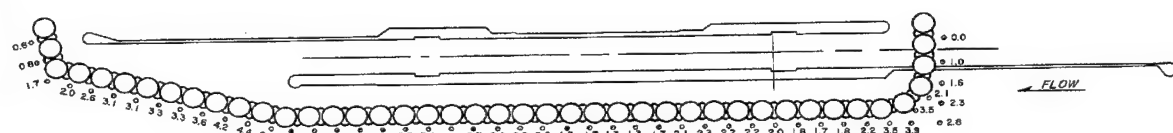


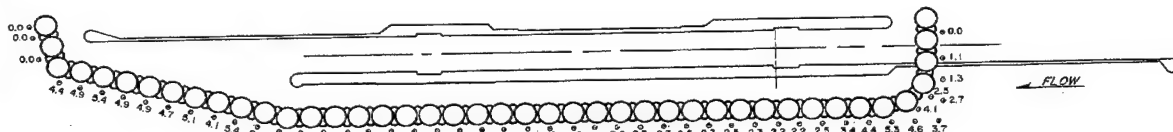
Plate 18



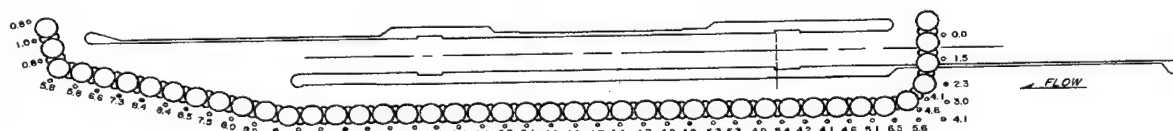




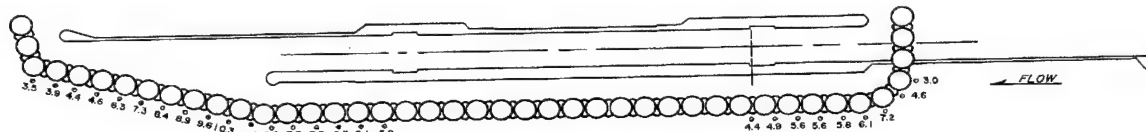
DISCHARGE: 25,000 CFS  
TAILWATER EL: 768.3 FT



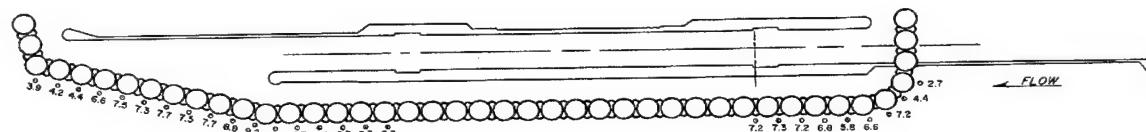
DISCHARGE: 51,800 CFS  
TAILWATER EL: 774.4 FT



DISCHARGE: 107,500 CFS  
TAILWATER EL: 784.8 FT



DISCHARGE: 157,000 CFS  
TAILWATER EL: 792.4 FT



DISCHARGE: 197,000 CFS  
TAILWATER EL: 798.0 FT

#### LEGEND

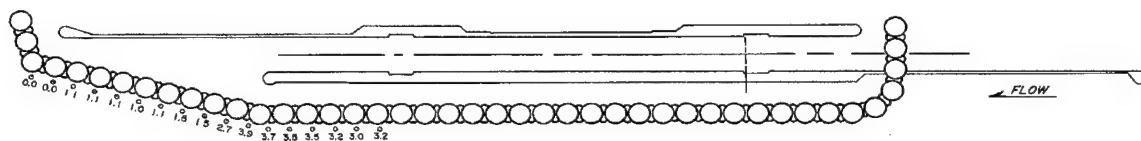
NOTE: 3.2 MEAN VELOCITY IN FEET PER SECOND  
SPOT VELOCITIES TAKEN 1.0 FT OFF  
COFFERDAM CELLS 5.0 FT ABOVE  
RIVERBED AT 50.0 FT INTERVALS  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO NGVD

MODEL STUDY OF  
GRAYS LANDING LOCK AND DAM  
MONONGAHELA RIVER

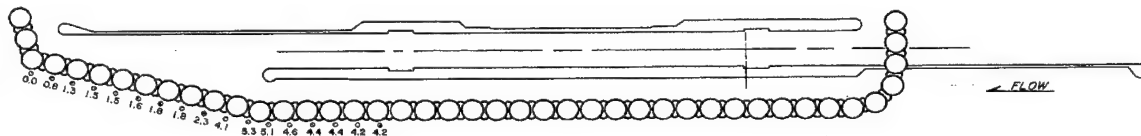
SPOT VELOCITIES  
LOCK COFFERDAM  
EXISTING ICE BREAKER CELLS IN

#### SCALES

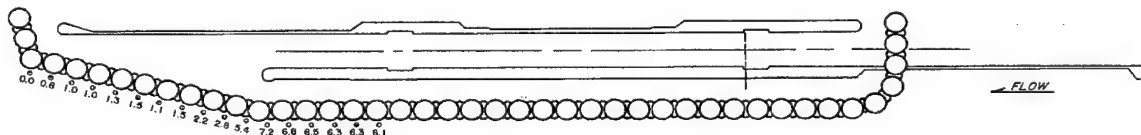
PROTOTYPE 200 0 200 FT  
MODEL 2 0 2 FT



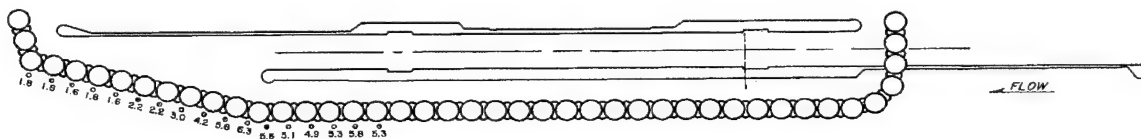
DISCHARGE: 25,000 CFS  
TAILWATER EL: 768.3 FT



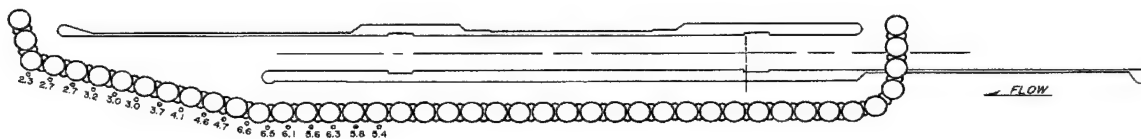
DISCHARGE: 51,800 CFS  
TAILWATER EL: 774.4 FT



DISCHARGE: 107,500 CFS  
TAILWATER EL: 784.8 FT



DISCHARGE: 157,000 CFS  
TAILWATER EL: 792.4 FT



DISCHARGE: 197,000 CFS  
TAILWATER EL: 798.0 FT

#### LEGEND

3.2 MEAN VELOCITY IN FEET PER SECOND  
NOTE: SPOT VELOCITIES TAKEN 10.0 FT OFF COFFERDAM CELLS 5.0 FT ABOVE RIVERBED AT 50.0 FT INTERVALS  
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

MODEL STUDY OF  
GRAYS LANDING LOCK AND DAM  
MONONGAHELA RIVER

#### SPOT VELOCITIES

LOCK COFFERDAM  
EXISTING ICE BREAKER CELLS OUT

#### SCALES

PROTOTYPE 200 0 200 FT  
MODEL 5 0 5 FT

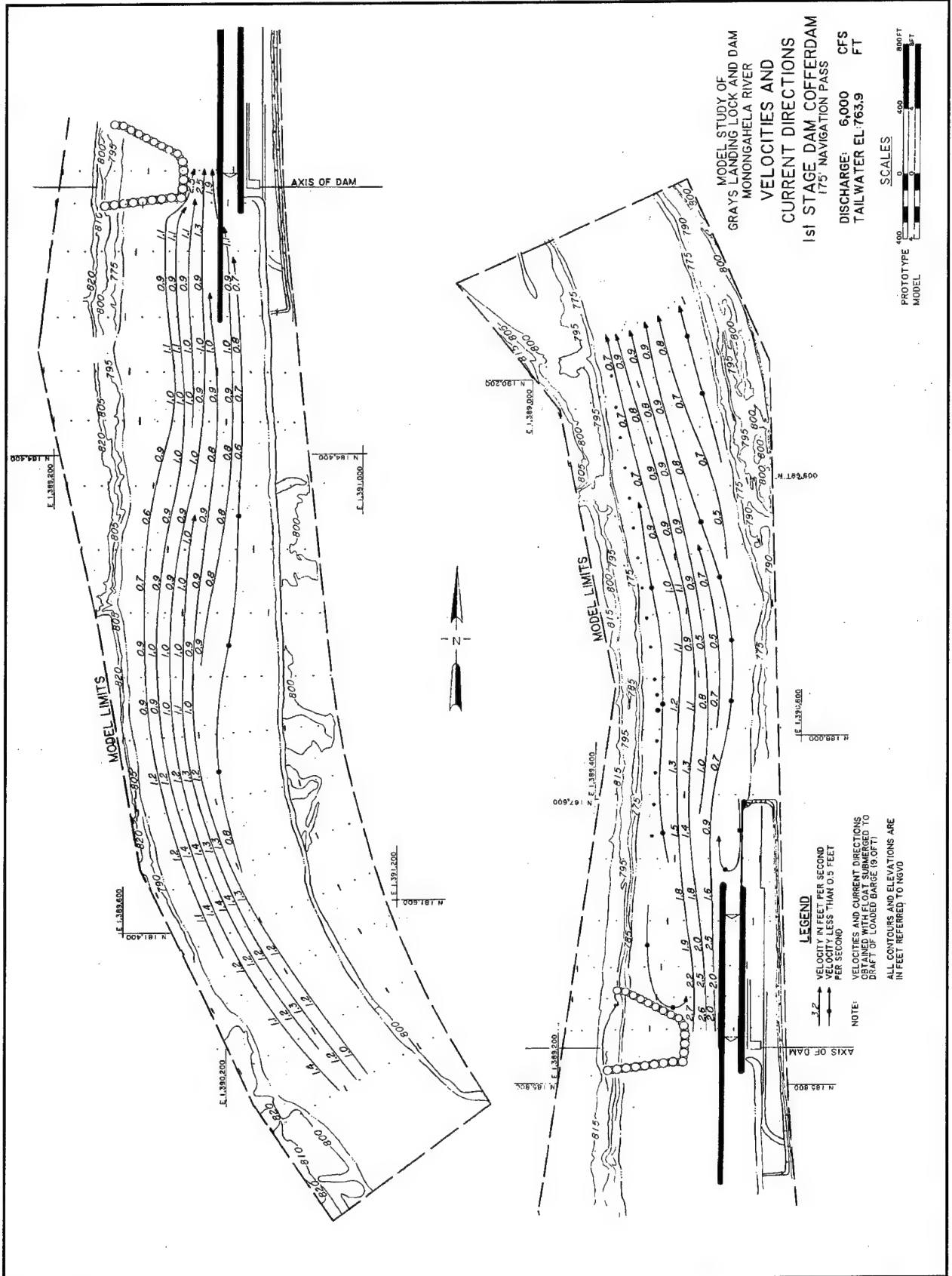


Plate 22

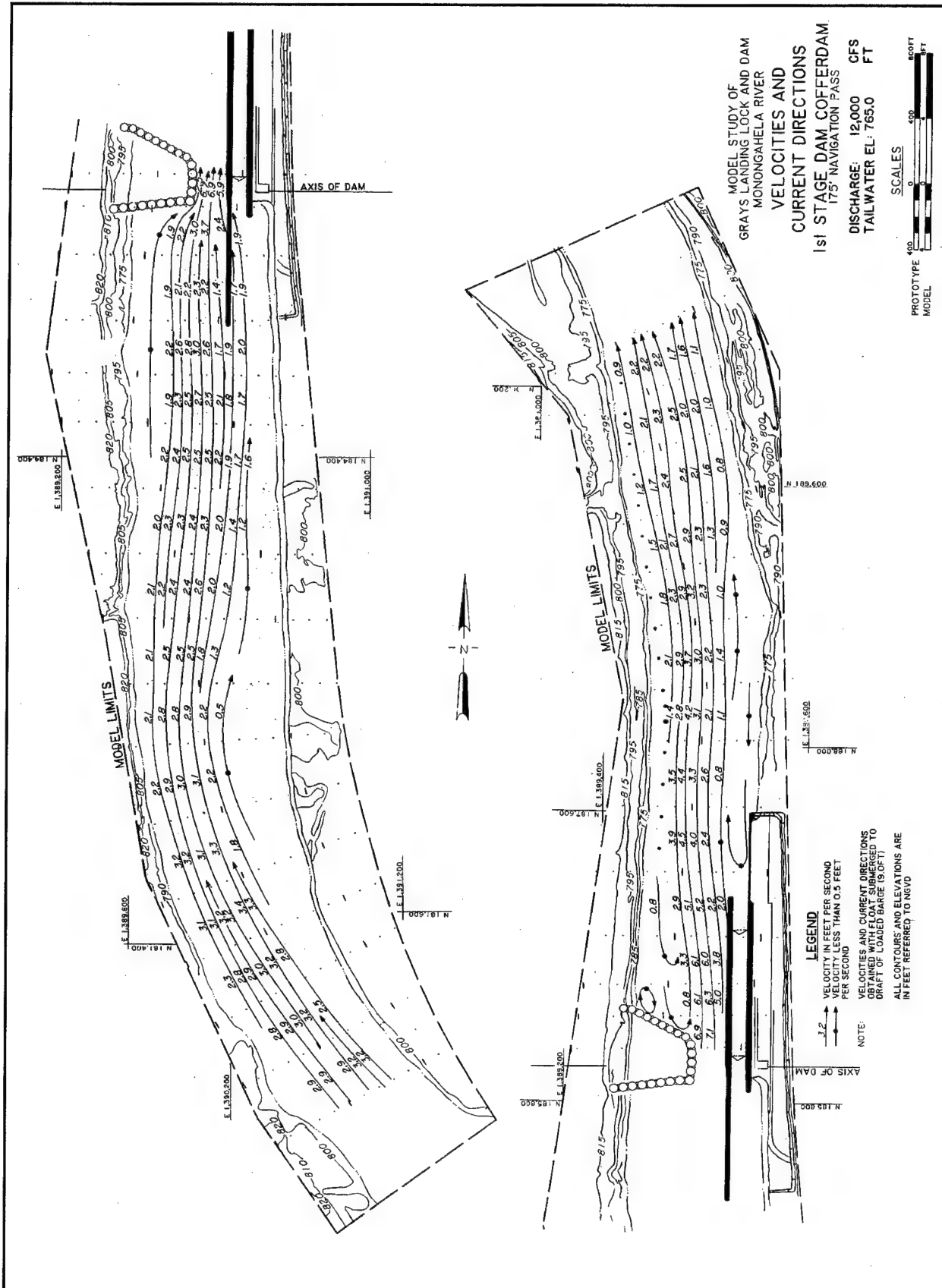


Plate 23

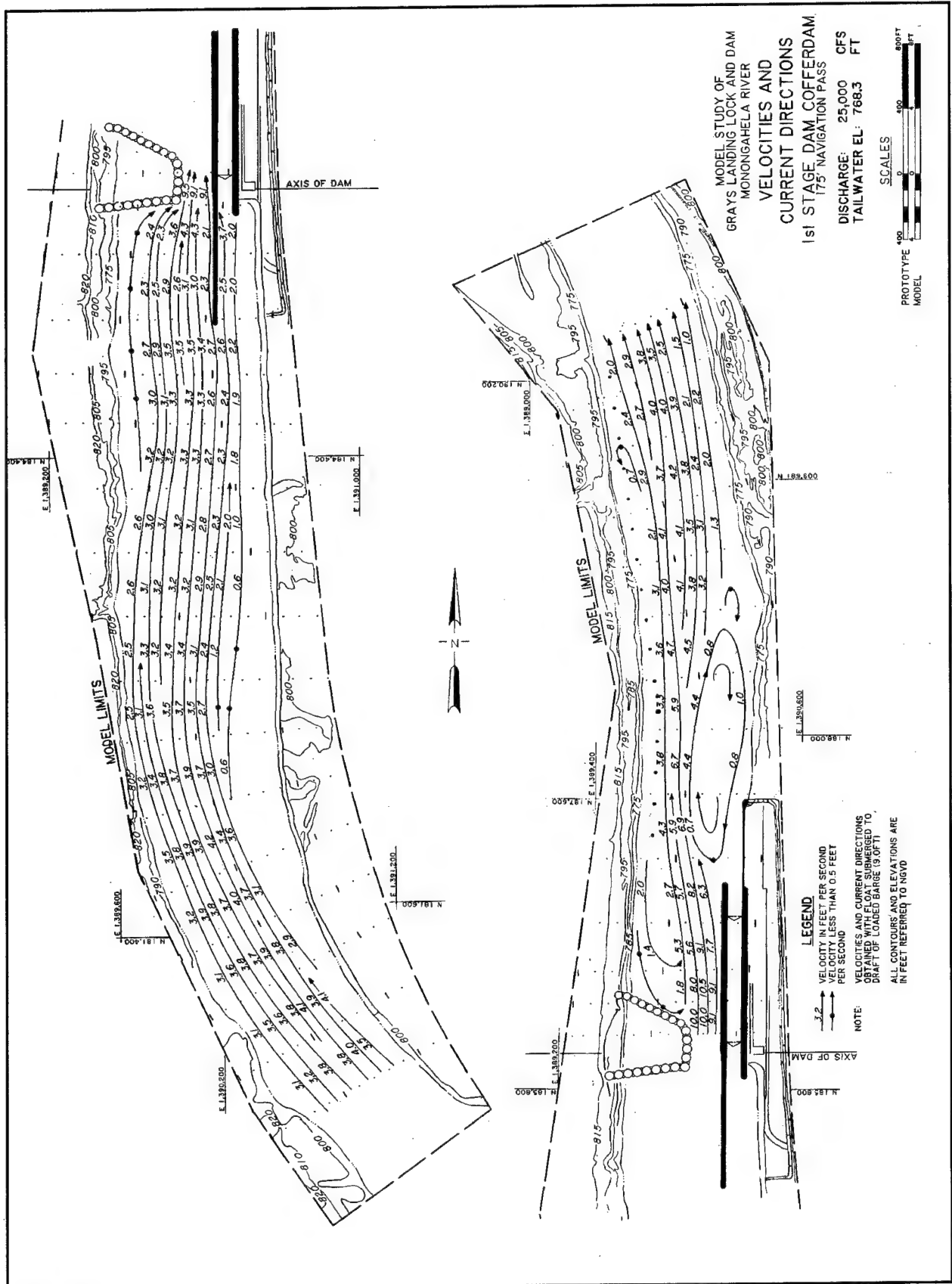
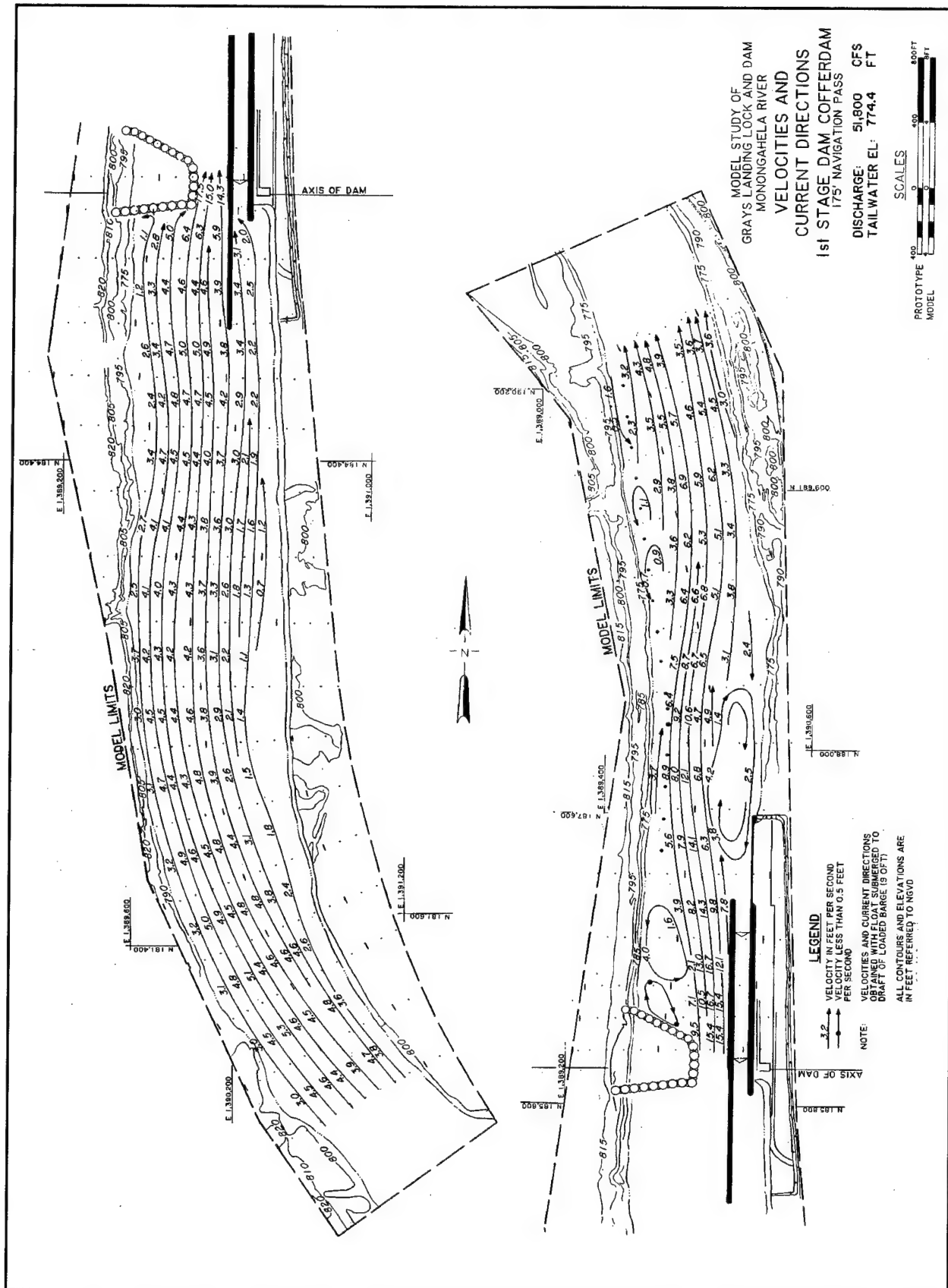


Plate 24



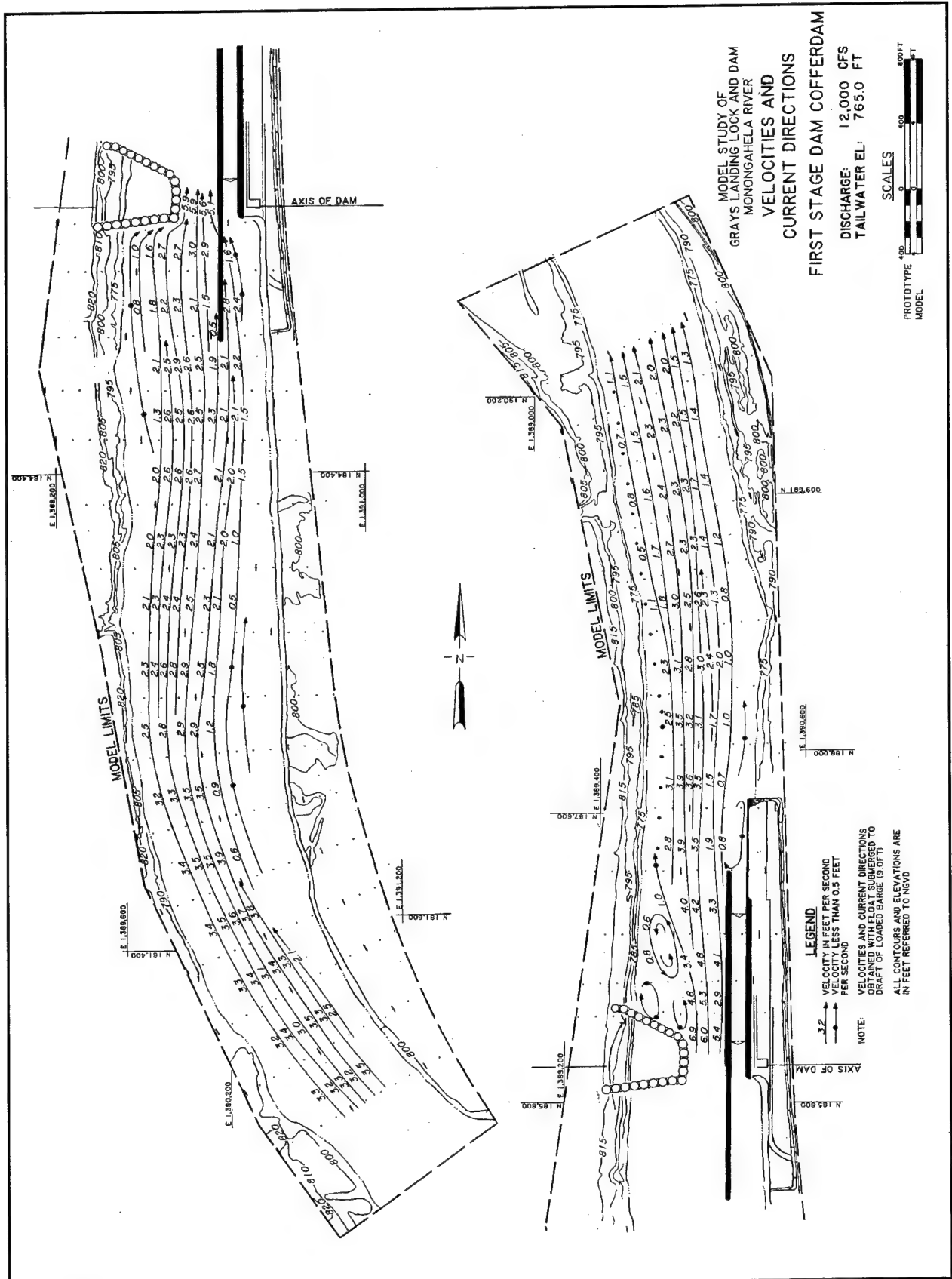
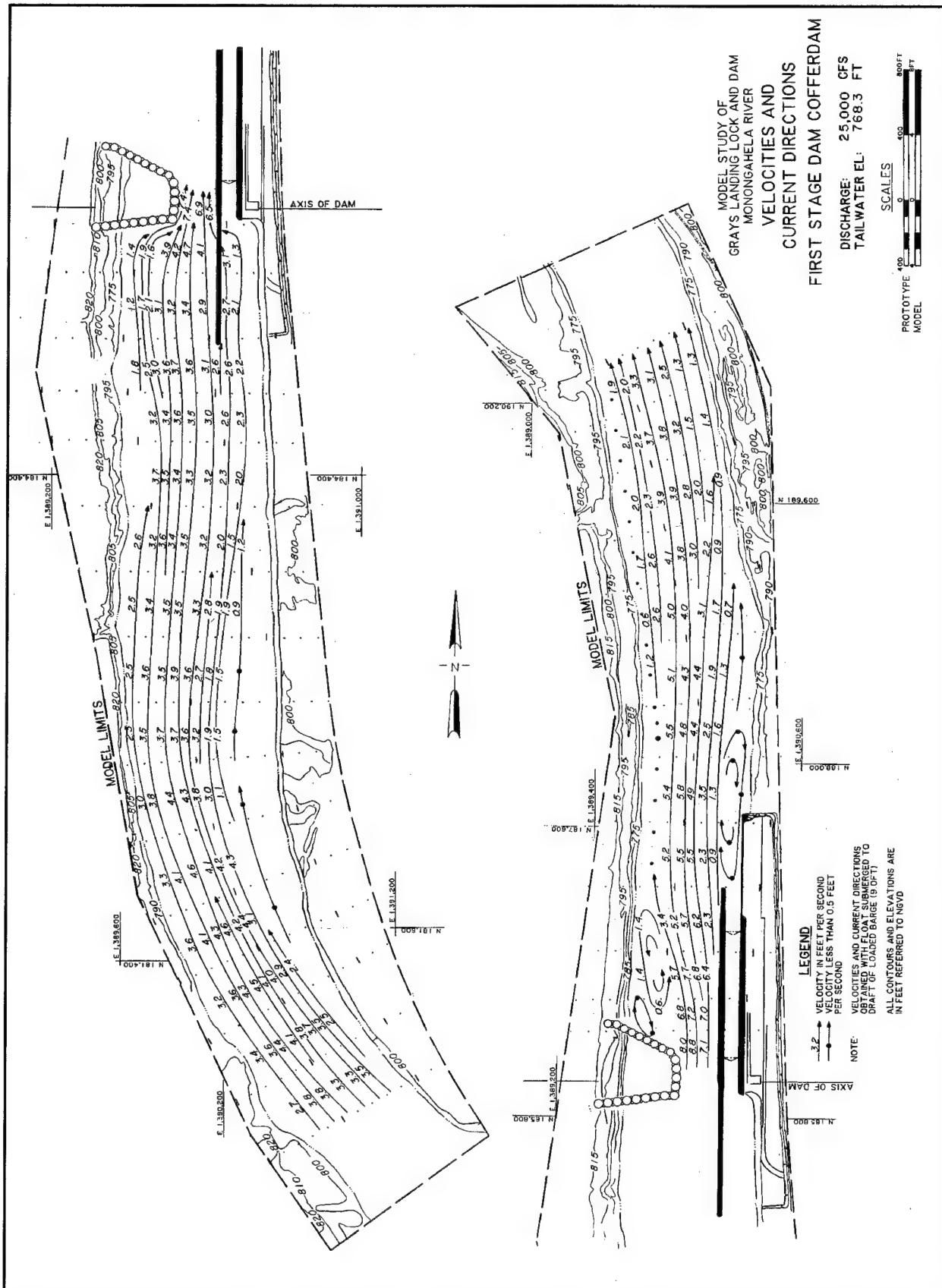
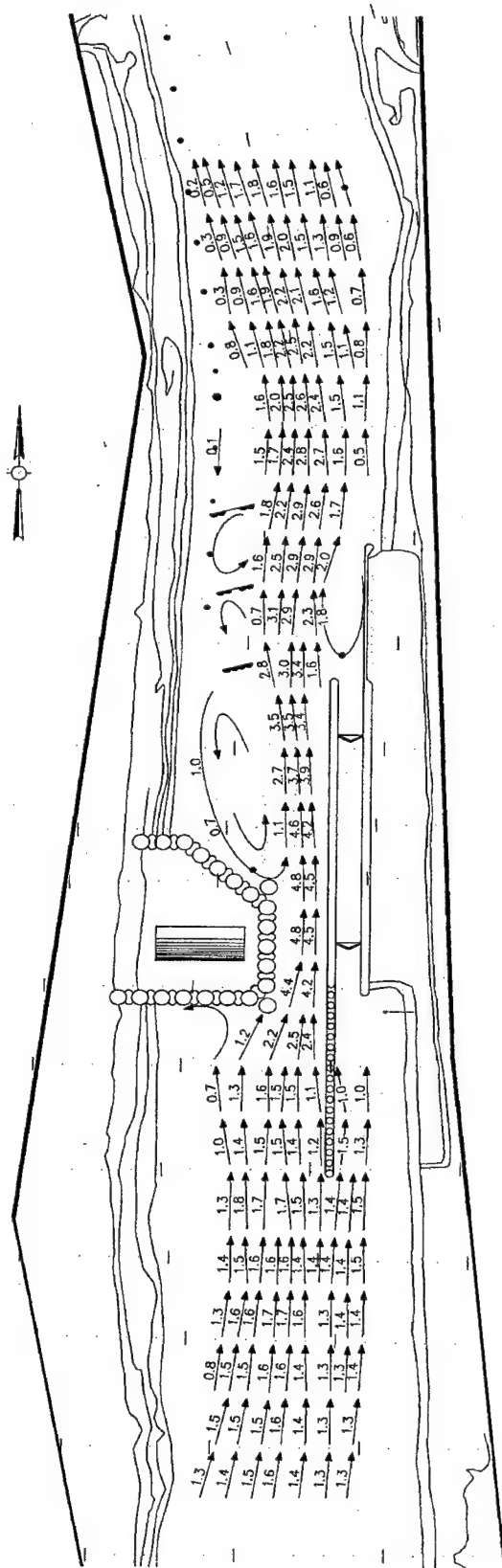


Plate 26

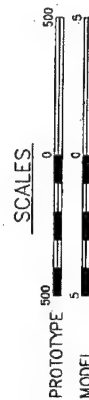








MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
VELOCITIES AND  
CURRENT DIRECTIONS  
1ST STAGE OF DAM COFFERDAM  
PLAN C  
DISCHARGE: 6,000 CFS  
TAILWATER EL: 763.9 FT

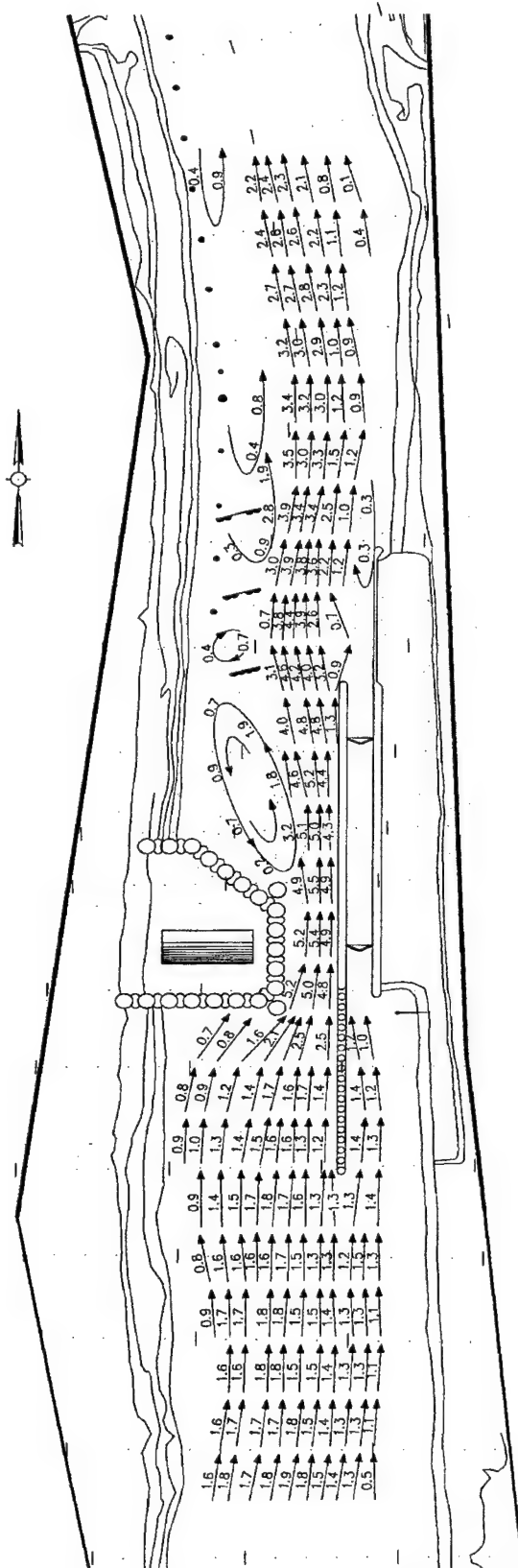


LEGEND

VELOCITY IN FEET PER SECOND  
VELOCITY LESS THAN 0.5 FEET  
PER SECOND



NOTE :  
VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED BARGE ( 9.0 FT )  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
VELOCITIES AND  
CURRENT DIRECTIONS  
1ST STAGE OF DAM COFFERDAM  
PLAN C  
DISCHARGE: 9000 CFS  
TAILWATER EL: 764.5 FT

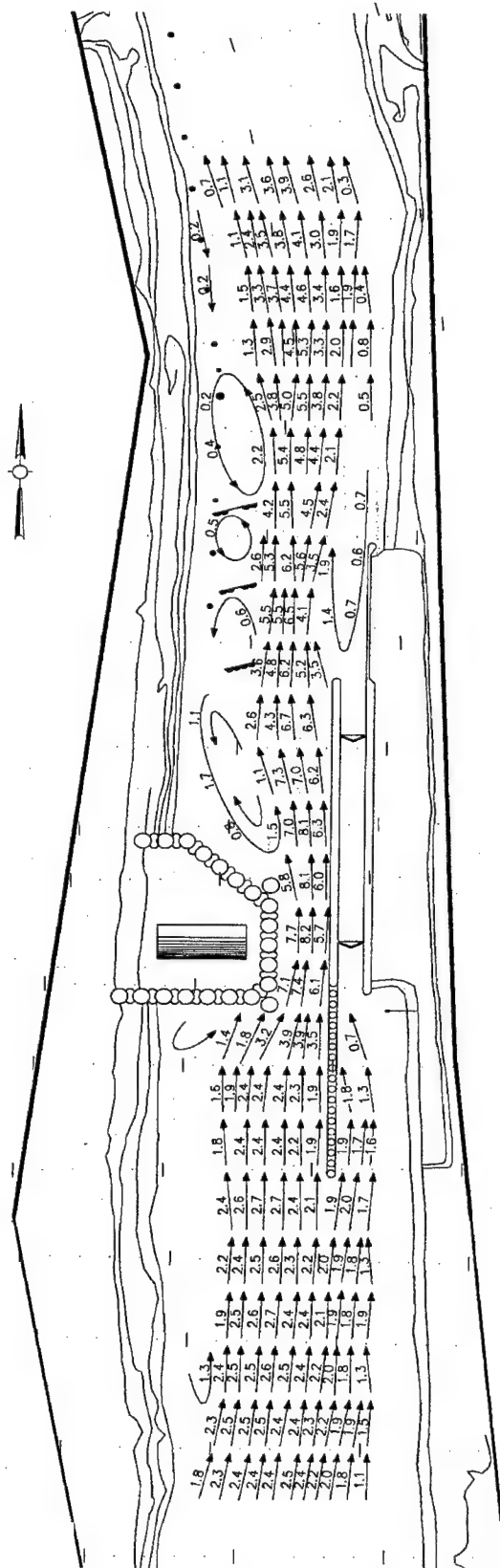


# LEGEND

VELOCITY IN FEET PER SECOND  
VELOCITY LESS THAN 0.5 FEET  
PER SECOND



NOTE : VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED BARGE ( 8.0 FT )  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO GROUND RIVER DATUM



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
VELOCITIES AND  
CURRENT DIRECTIONS  
1ST STAGE OF DAM COFFERDAM  
PLAN C  
DISCHARGE: 12,000 CFS  
TAILWATER EL: 765.0 FT

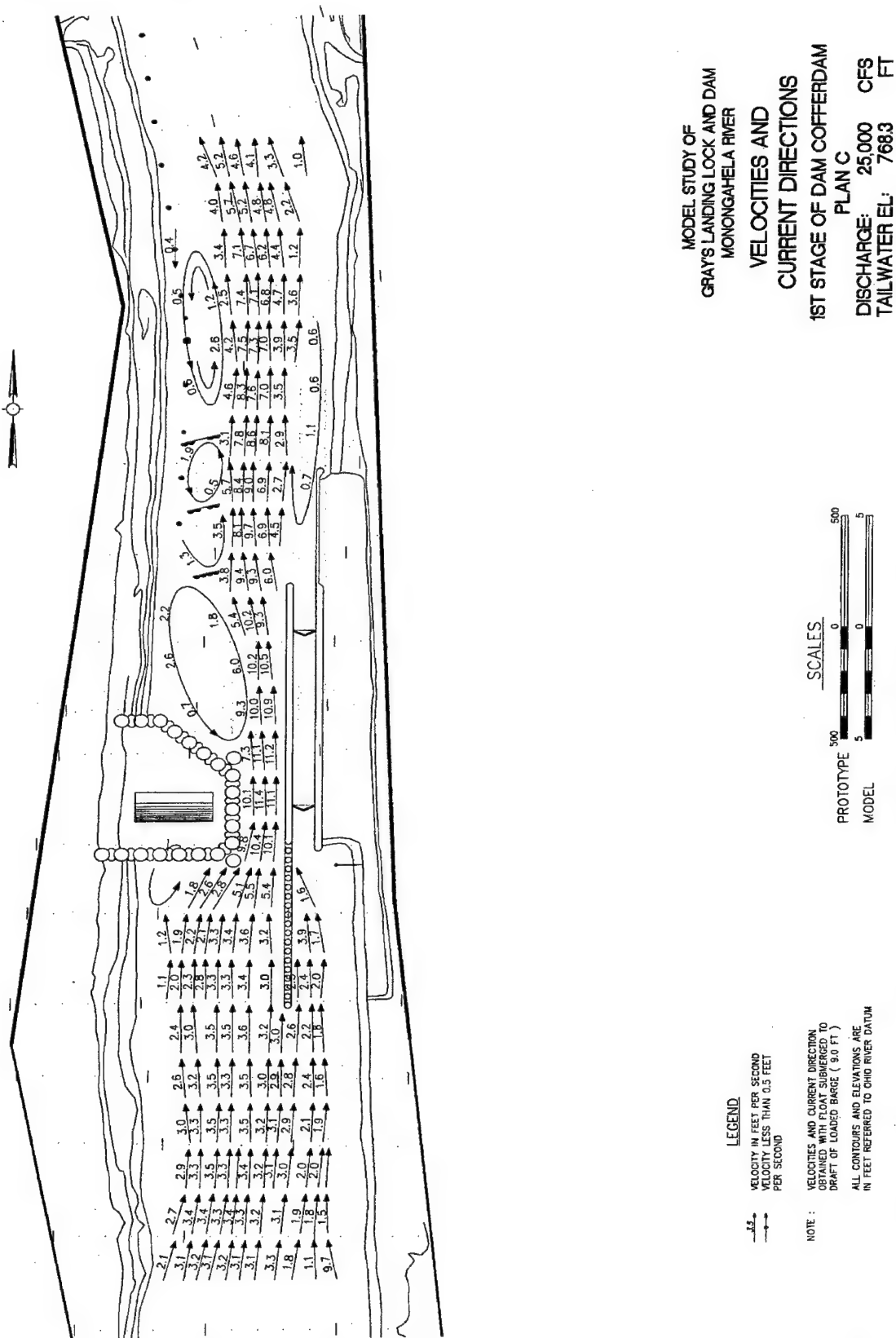


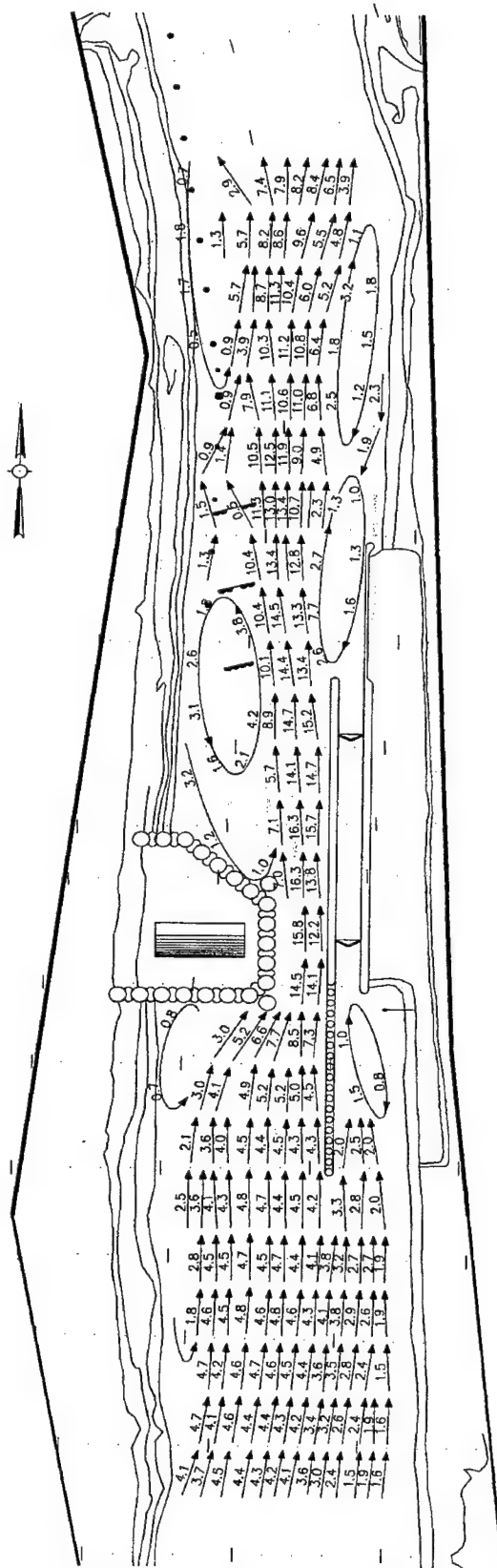
**LEGEND**

VELOCITY IN FEET PER SECOND  
VELOCITY LESS THAN 0.5 FEET  
PER SECOND

NOTE : VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED BARGE ( 9.0 FT )

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM





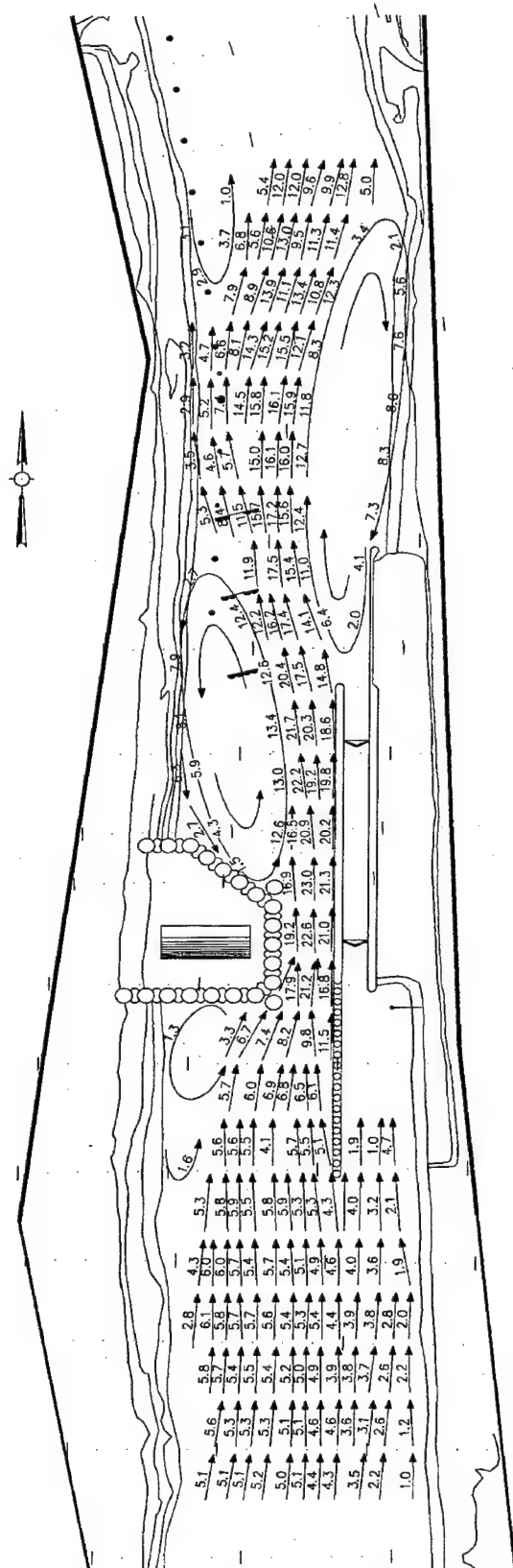
MODEL STUDY OF  
GRAYS LANDING LOCK AND DAM  
MONONGAHELA RIVER  
VELOCITIES AND  
CURRENT DIRECTIONS  
1ST STAGE OF DAM COFFERDAM  
PLAN C  
DISCHARGE: 51,800 CFS  
TAILWATER EL: 774.4 FT



LEGEND

VELOCITY IN FEET PER SECOND  
VELOCITY LESS THAN 0.5 FEET  
PER SECOND

NOTE: VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED BARGE ( 9.0 FT )  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
VELOCITIES AND  
CURRENT DIRECTIONS  
1ST STAGE OF DAM COFFERDAM  
PLAN C  
DISCHARGE: 107,500 CFS  
TAILWATER EL: 784.8 FT

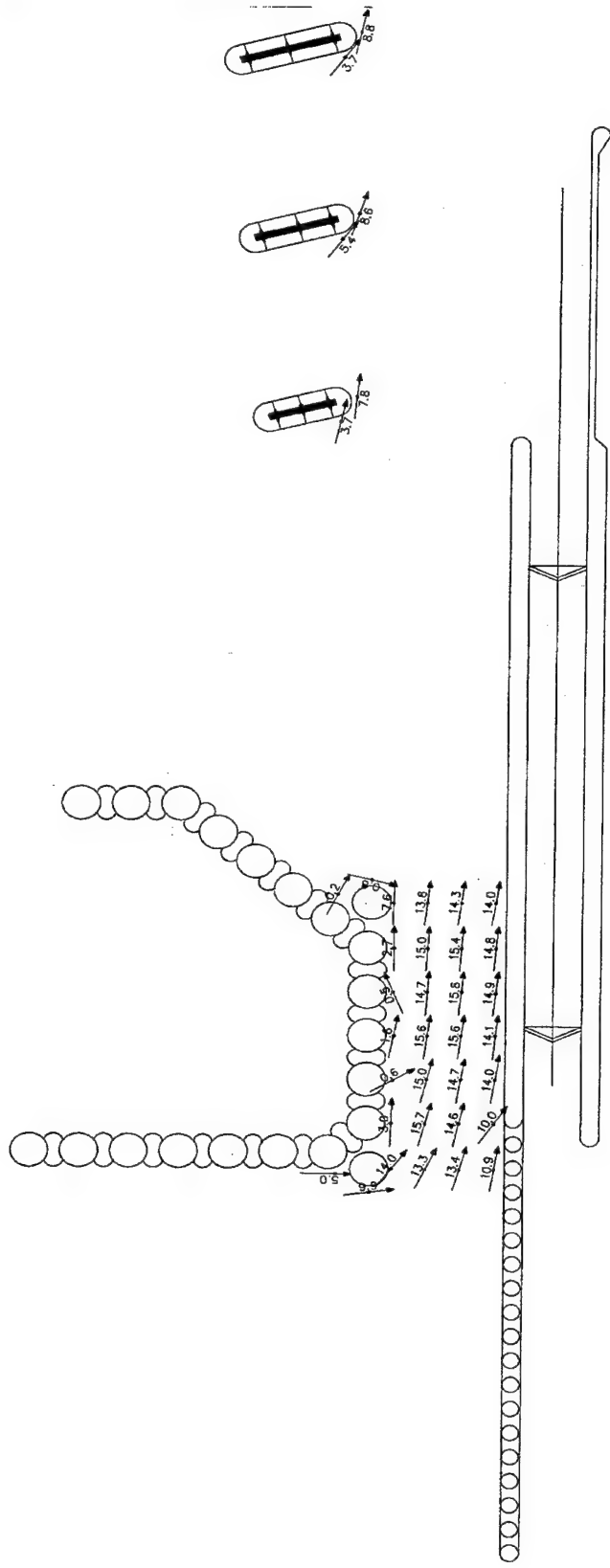


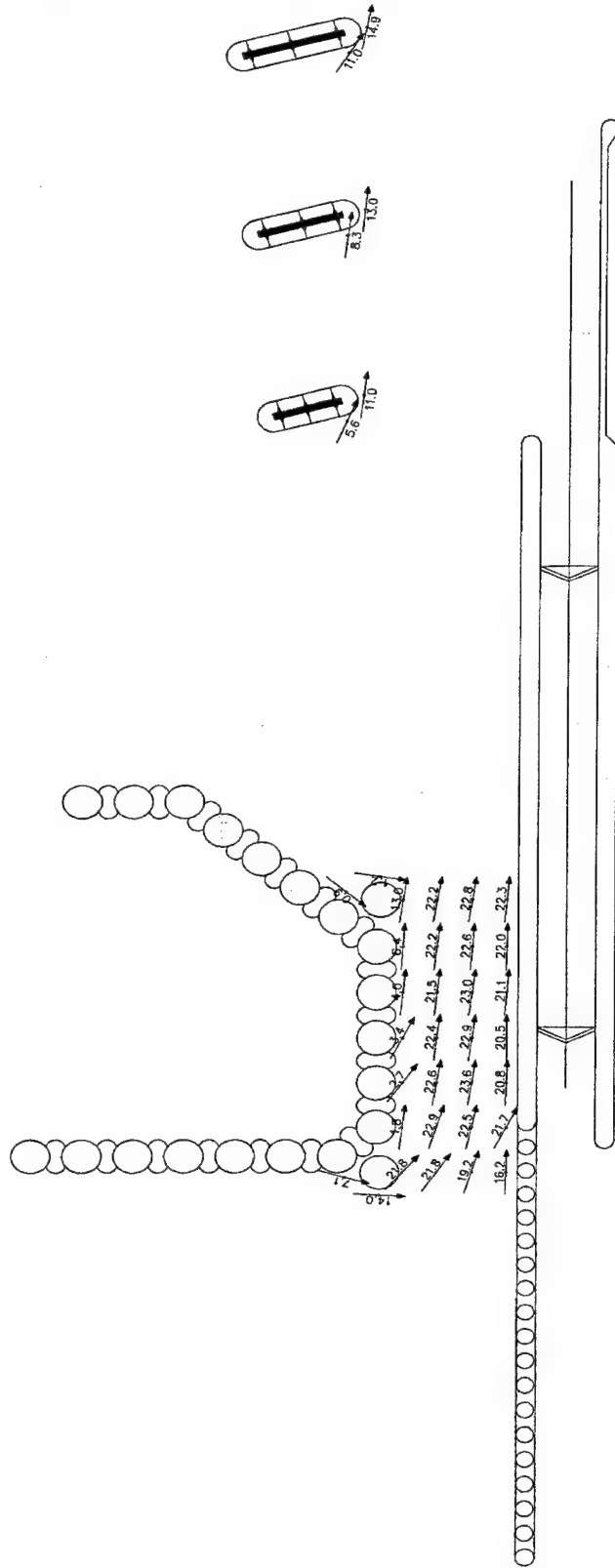
# LEGEND

VELOCITY IN FEET PER SECOND  
VALUES LESS THAN 0.5 FEET  
PER SECOND

NOTE :  
VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED BARGE ( 5.0 FT )  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM







MODEL STUDY OF  
GRAYS LANDING LOCK AND DAM  
MONONGAHELA RIVER

METER VELOCITIES  
1ST STAGE OF DAM COFFERDAM  
PLAN C  
175' CHANNEL  
LOCK CLOSED

DISCHARGE: 107,500 CFS  
TAILWATER EL: 784.8 FT

LEGEND

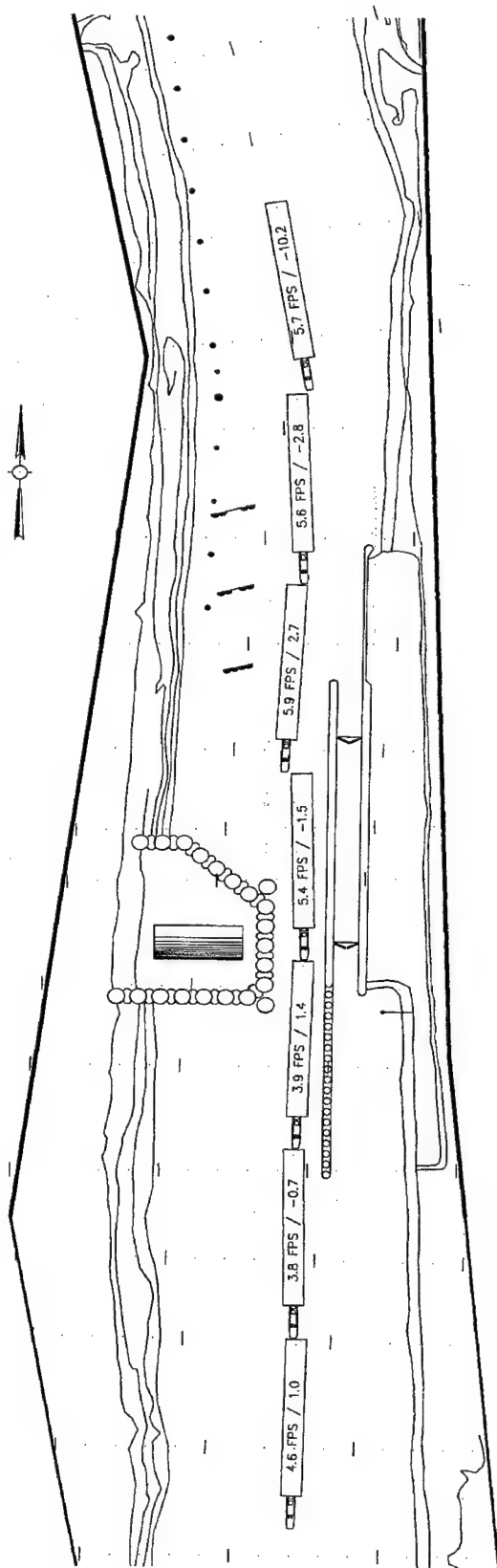
1.2

MEAN VELOCITIES IN FEET PER SECOND

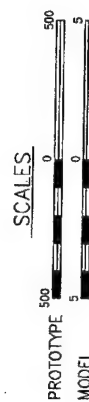
NOTE:  
METER VELOCITIES MEASURED 5.0FT  
ABOVE BOTTOM  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO NGVD

SCALES





MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
DOWNBOUND TOW PATH  
1ST STAGE OF DAM COFFERDAM  
PLAN C  
DISCHARGE: 6,000 CFS  
TAILWATER EL: 763.9 FT

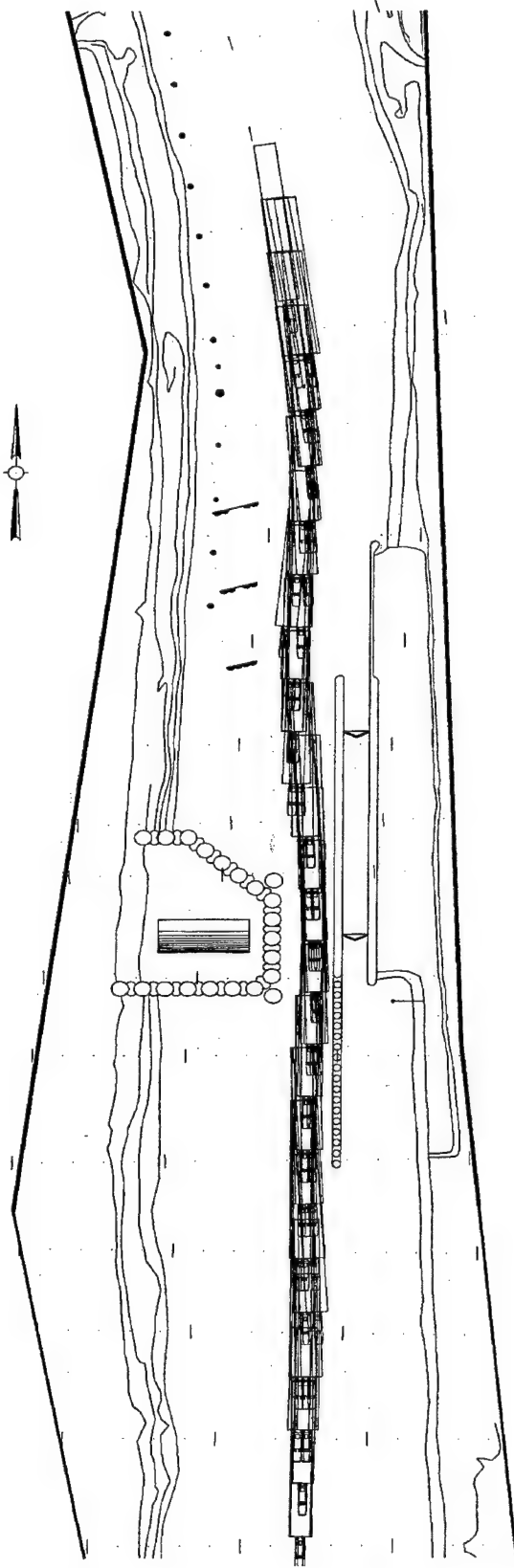


LEGEND

SPEED OF TOW: 3.5 FPS / 1.2  
70-FT X 705-FT 6-BARGE TOW

ANGLE OF TOW

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



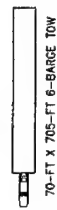
MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

DOWNBOUND TOW PATHS

MULTIPLE RUNS  
1ST STAGE OF DAM COFFERDAM  
PLAN C

DISCHARGE: 6,000 CFS  
TAILWATER EL: 763.9 FT

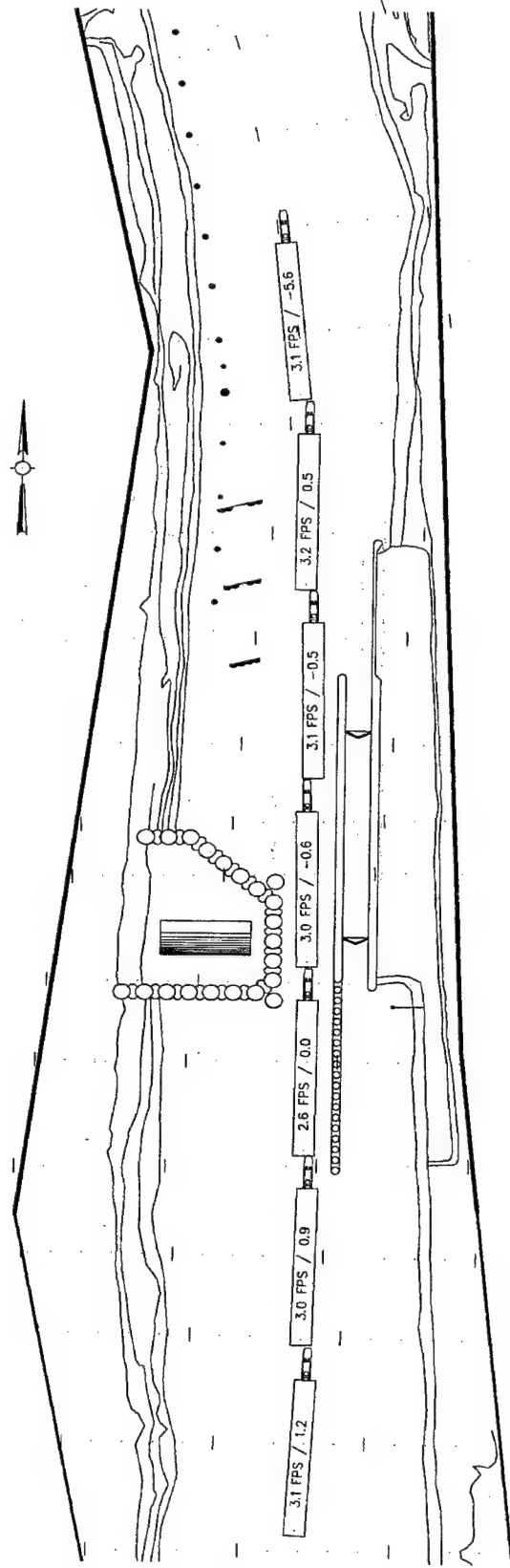
LEGEND



70-FT X 705-FT 6-BARGE TOW

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



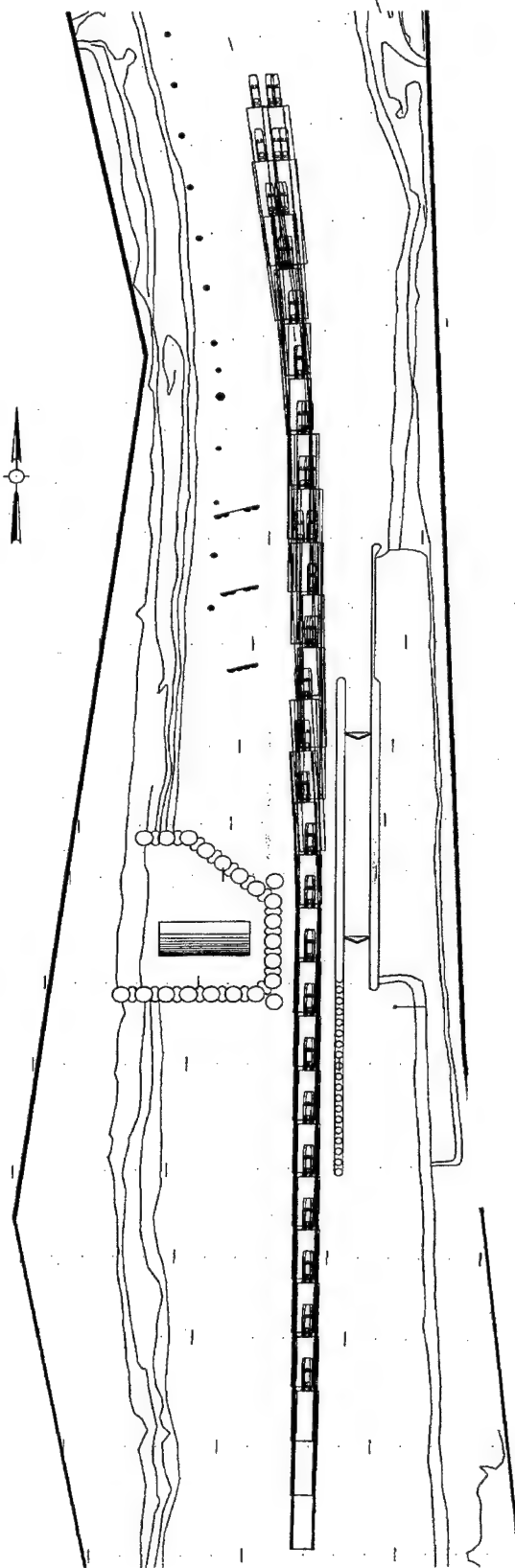


MODEL STUDY OF  
GRAYS LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPBOUND TOWPATH  
1ST STAGE OF DAM COFFERDAM  
PLAN C  
DISCHARGE: 6,000 CFS  
TAILWATER EL: 763.9 FT

LEGEND

SPEED OF TOW  
ANGLE OF TOW  
70-FT X 700-FT 6-BARGE TOW  
3.5 FPS / 1.2  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM





MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

UPBOUND TOW PATHS

MULTIPLE RUNS  
1ST STAGE OF DAM COFFERDAM  
PLAN C

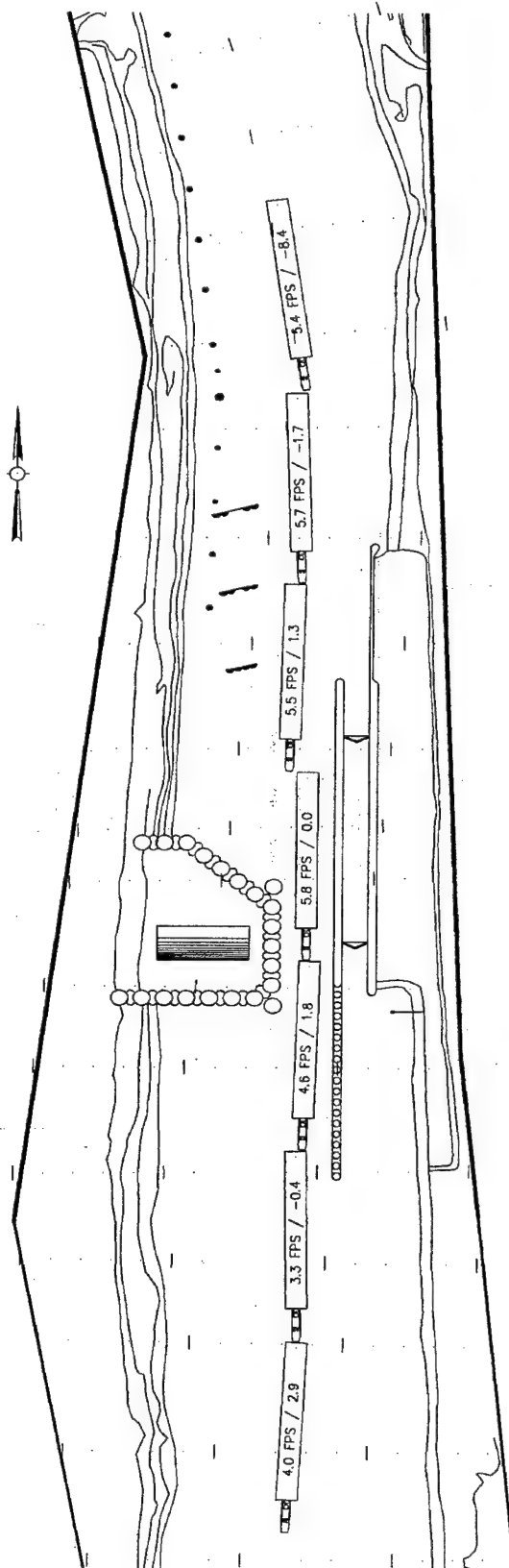
DISCHARGE: 6,000 CFS  
TAILWATER EL: 763.9 FT

LEGEND

70-FT X 705-FT 6-BARGE TOW

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM





MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
DOWNBOUND TOW PATH  
1ST STAGE OF DAM COFFERDAM  
PLAN C  
DISCHARGE: 9,000 CFS  
TAILWATER EL: 764.5 FT

LEGEND

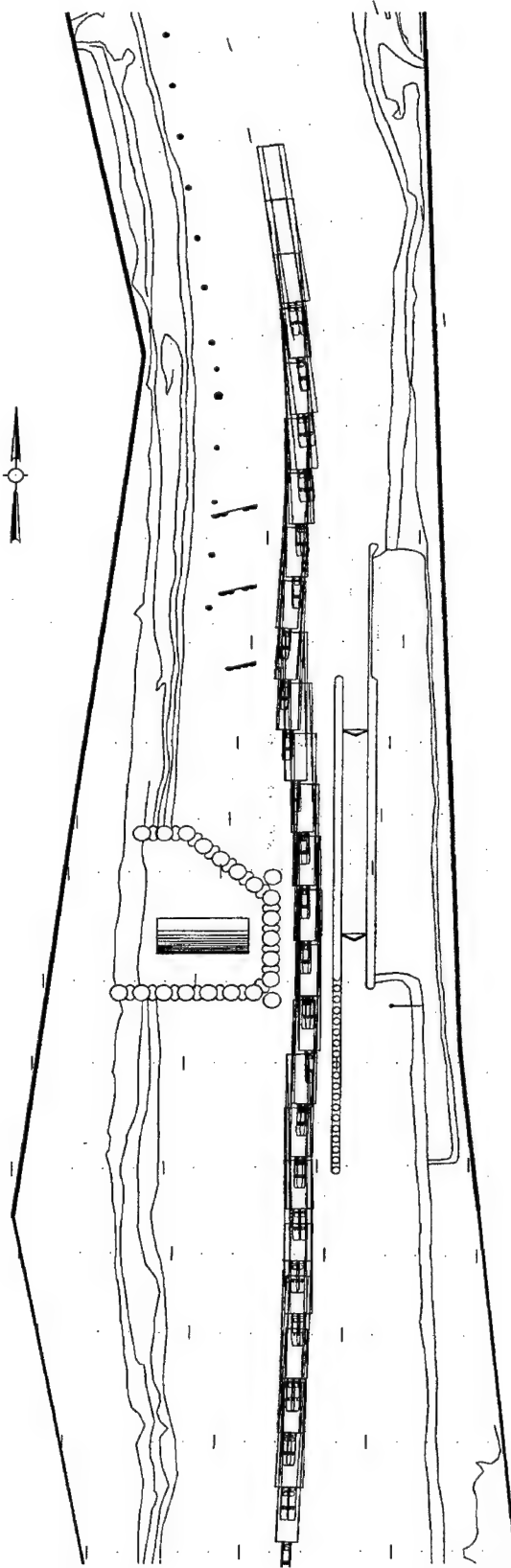
SPEED OF TOW  
70-FT X 705-FT 6-9ARGE TOW  
3.5 FPS / 1.2  
ANGLE OF TOW

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO CHD RIVER DATUM



SCALES





LEGEND

70-FT X 705-FT 6-BARGE TOW

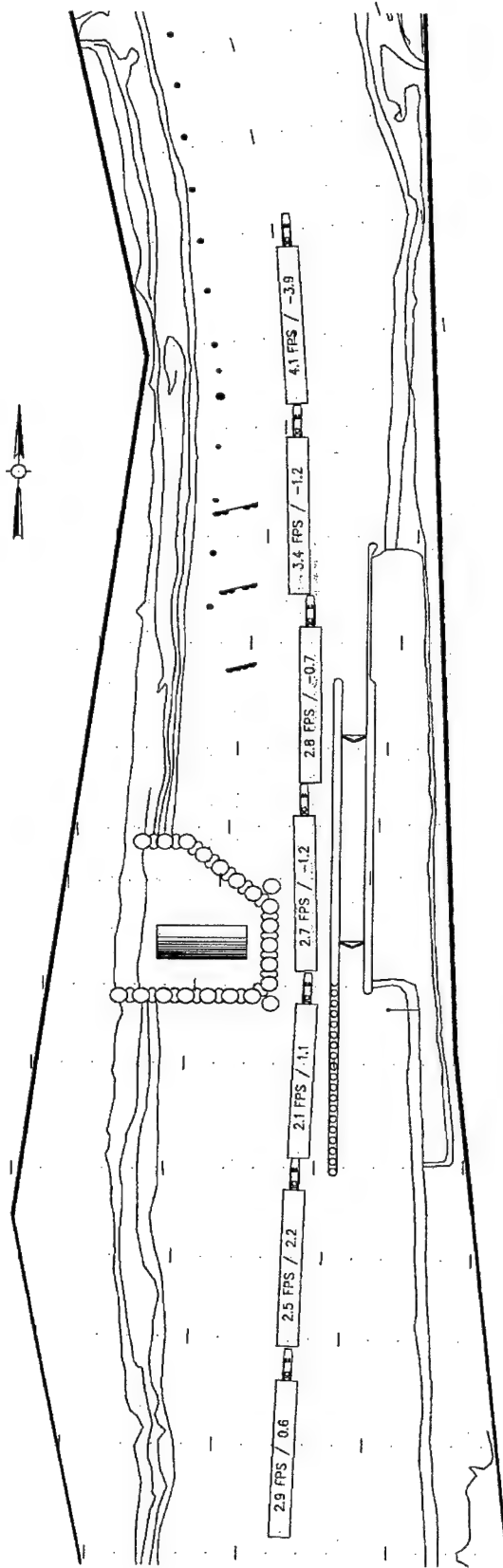
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO CHD RIVER DATUM

SCALES



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
DOWNBOUND TOW PATHS  
MULTIPLE RUNS  
1ST STAGE OF DAM COFFERDAM  
PLAN C  
DISCHARGE: 9000 CFS  
TAILWATER EL: 764.5 FT





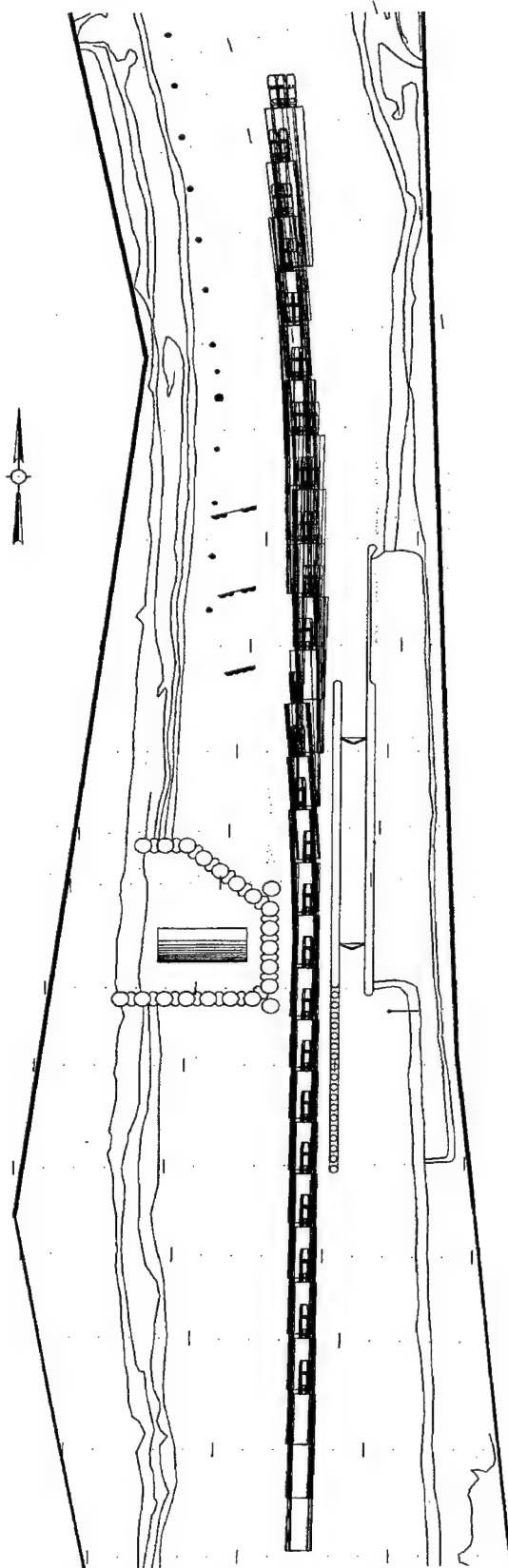
MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPBOUND TOW PATH  
1ST STAGE OF DAM COFFERDAM  
PLAN C  
DISCHARGE: 9,000 CFS  
TAILWATER EL: 764.5 FT



LEGEND

SPEED OF TOW 3.5 FPS / 1.2  
ANGLE OF TOW  
70-FT X 705-FT 6-BARGE TOW

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

UPBOUND TOW PATHS

MULTIPLE RUNS  
1ST STAGE OF DAM COFFERDAM  
PLAN C

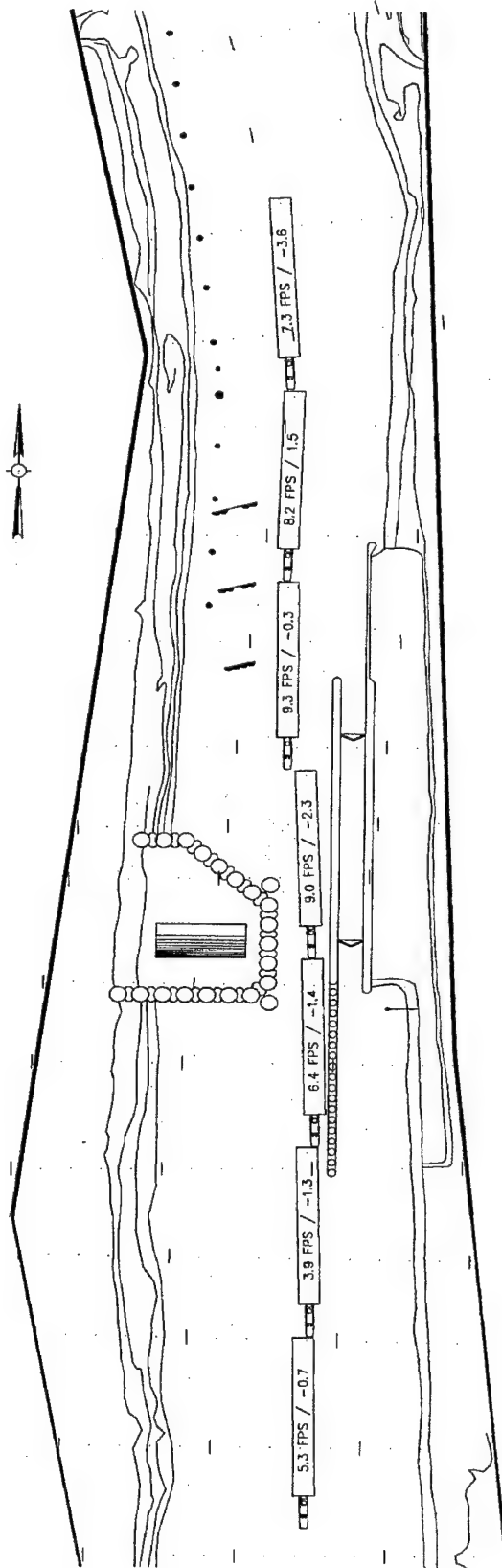
DISCHARGE: 9,000 CFS  
TAILWATER EL: 764.5 FT

LEGEND

70-FT X 705-FT 6-BARGE TOW

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM





MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
DOWNBOUND TOW PATH  
1ST STAGE OF DAM COFFERDAM  
PLAN C  
DISCHARGE: 12,000 CFS  
TAILWATER EL: 765.0 FT

LEGEND

SPEED OF TOW

ANGLE OF TOW

70-FT X 705-FT 6-BARGE TOW

3.5 FPS / 1.2

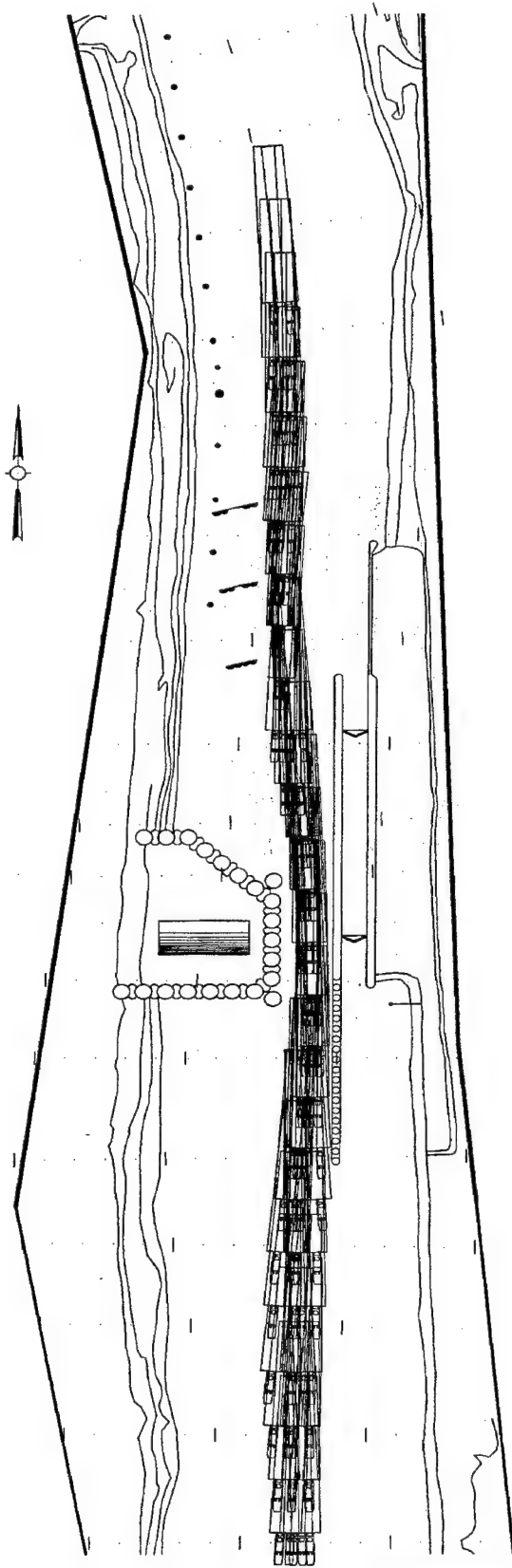
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

SCALES

PROTOTYPE

MODEL





MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

DOWNBOUND TOW PATHS

MULTIPLE RUNS  
1ST STAGE OF DAM COFFERDAM  
PLAN C

DISCHARGE: 12,000 CFS  
TAILWATER EL: 765.0 FT

LEGEND

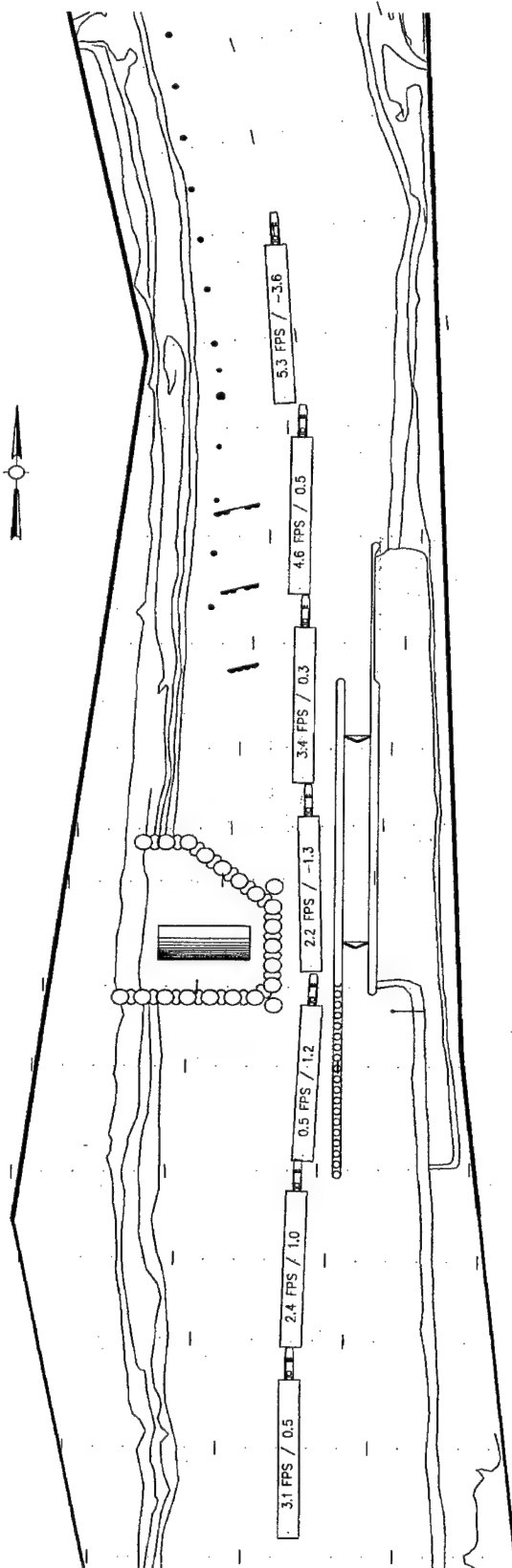


70-FT X 705-FT 6-BARGE TOW

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

SCALES

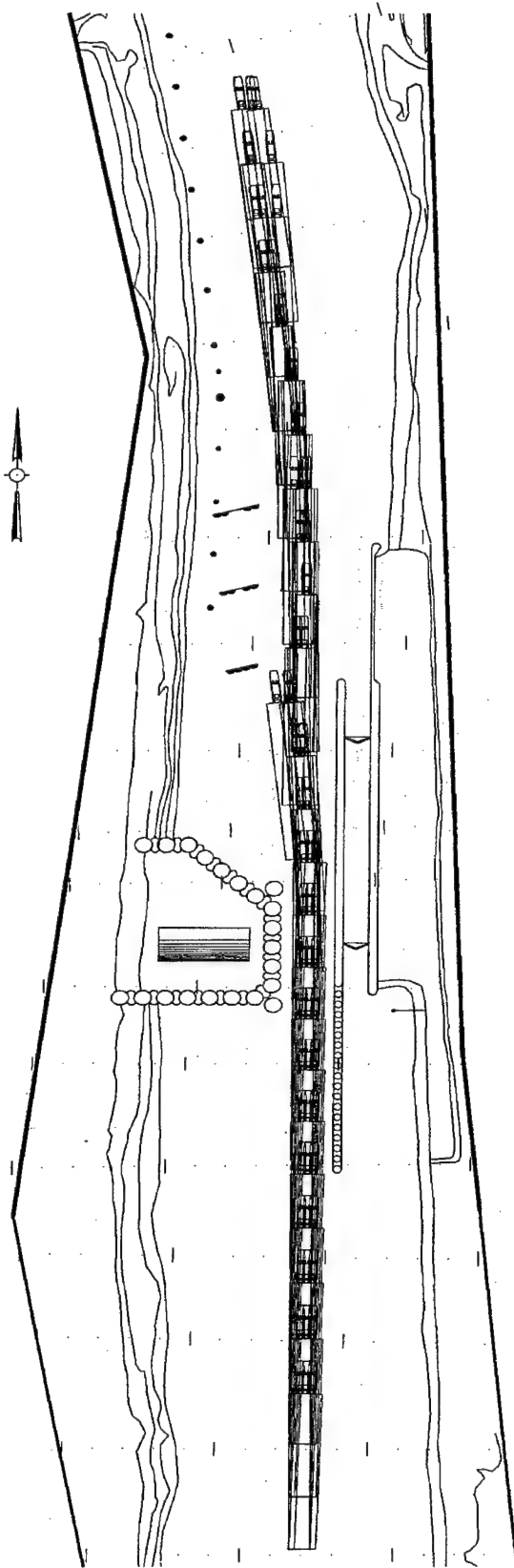




MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPBOUND TOW PATH  
1ST STAGE OF DAM COFFERDAM  
PLAN C  
DISCHARGE: 12,000 CFS  
TAIL WATER EL: 7650 FT

LEGEND  
SPEED OF TOW  
ANGLE OF TOW  
70-FT X 705-FT 6-BARGE TOW  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM





GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPBOUND TOW PATHS

MULTIPLE RUNS  
1ST STAGE OF DAM COFFERDAM  
PLAN C

DISCHARGE: 12,000 CFS  
TAILWATER EL: 765.0 FT

LEGEND

70-FT X 705-FT 6-BARGE TOW

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

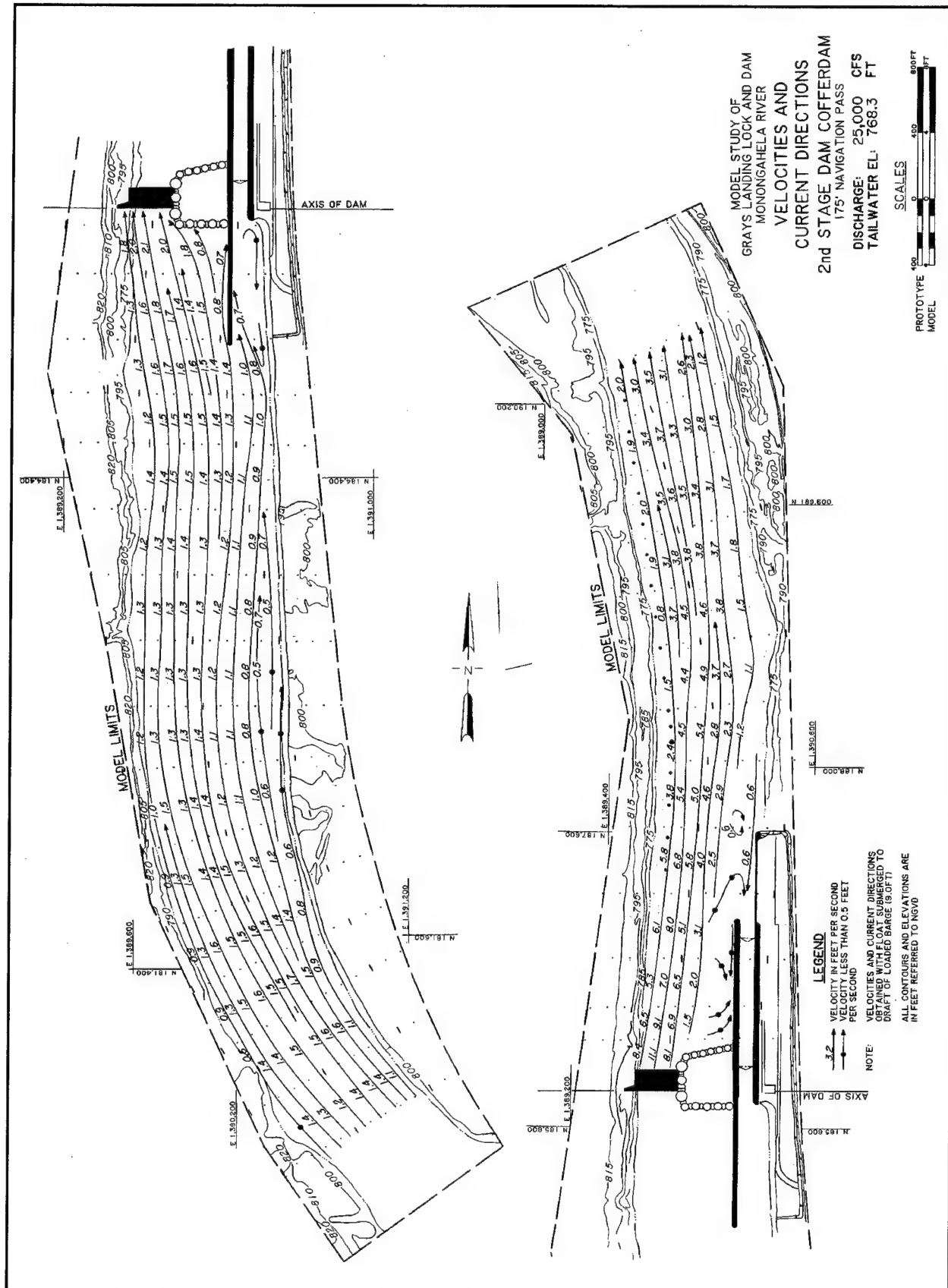
SCALES











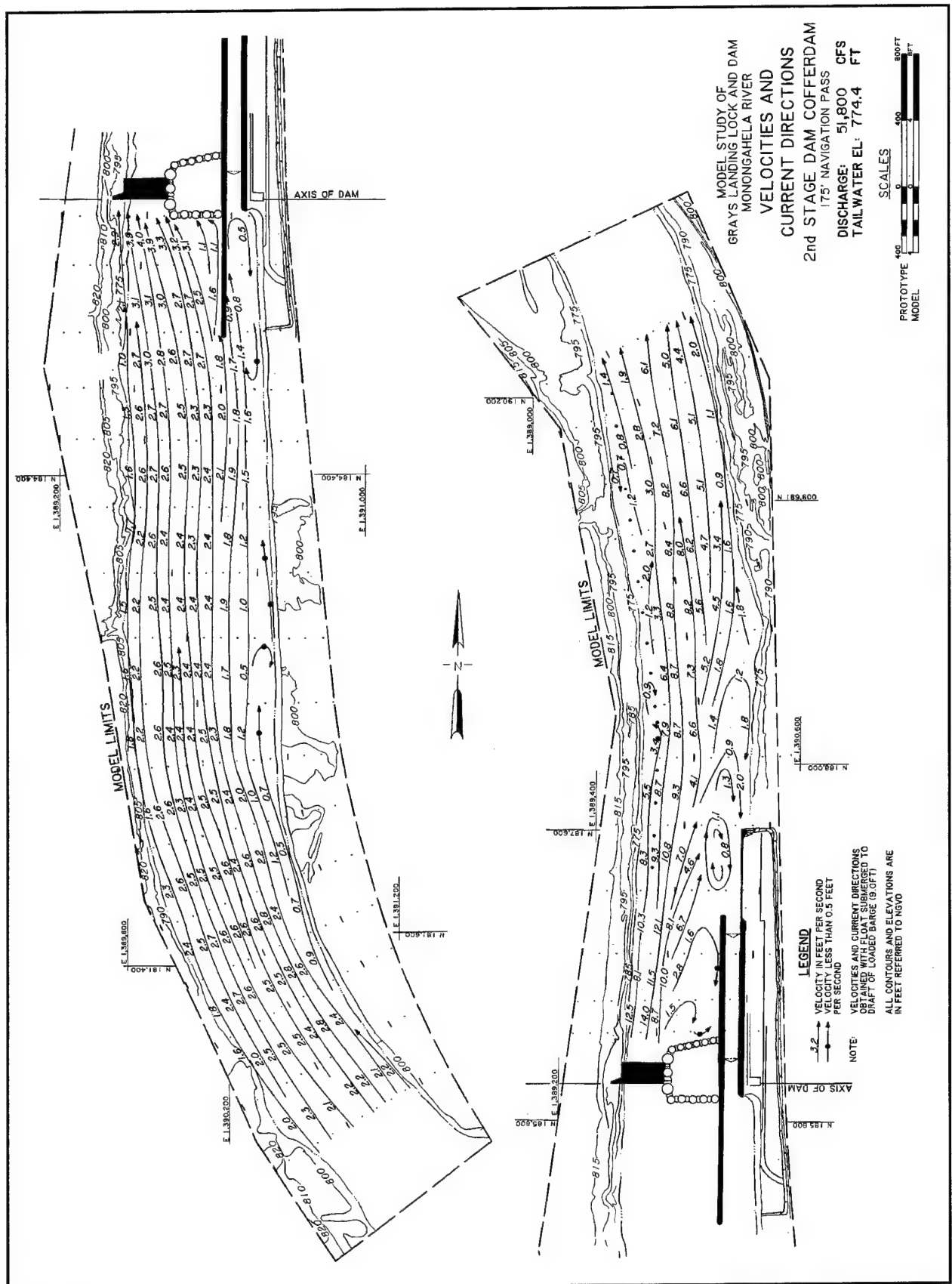
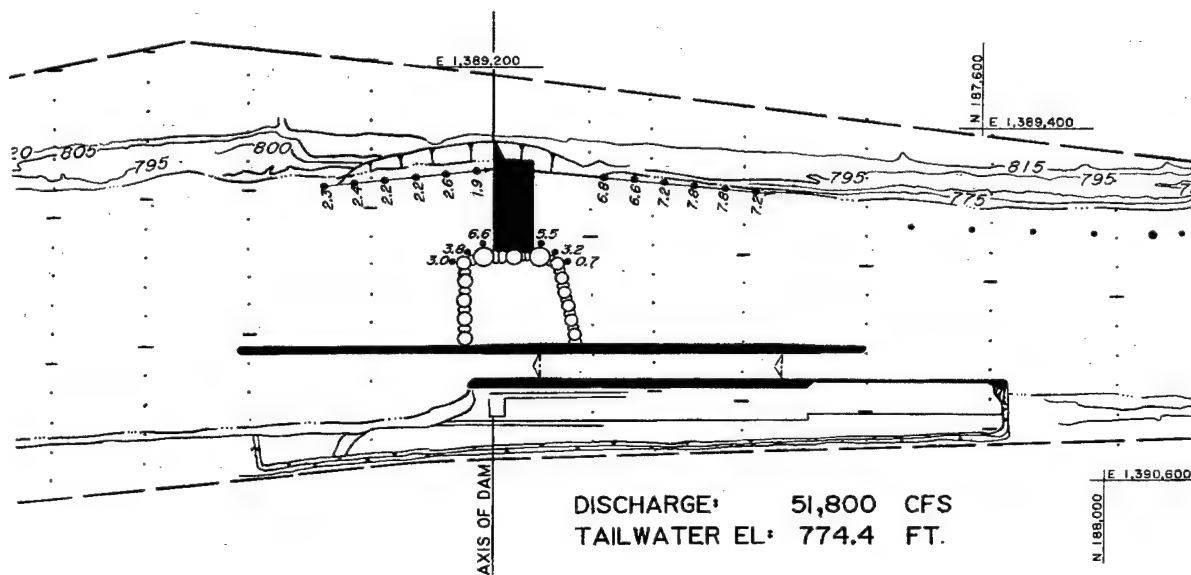
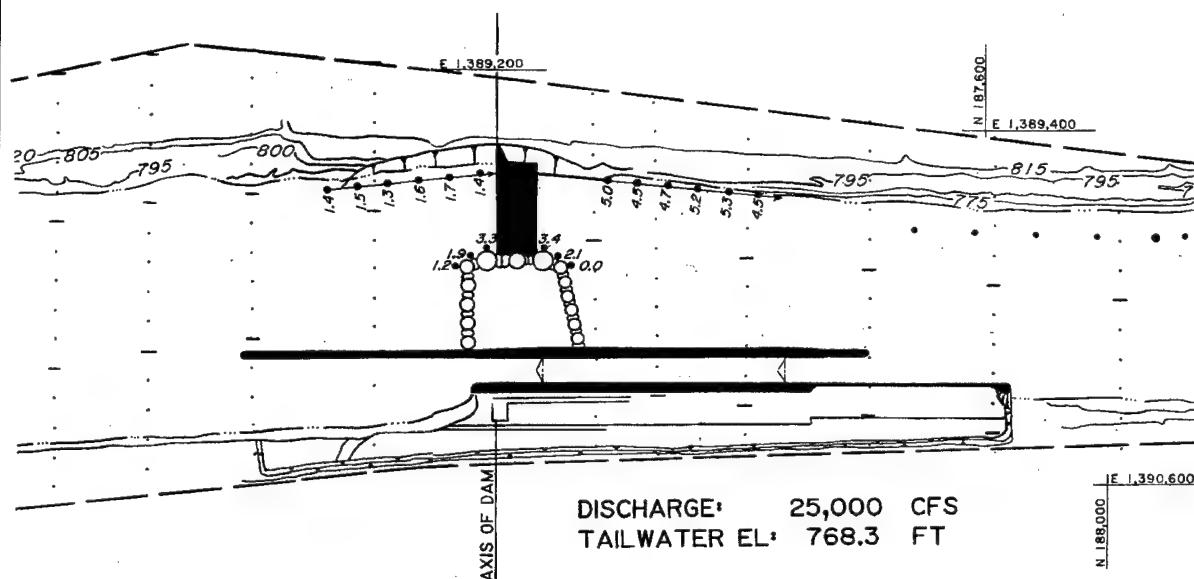


Plate 52



MODEL STUDY OF  
GRAYS LANDING LOCK AND DAM  
MONONGAHELA RIVER

SPOT VELOCITIES

2nd STAGE DAM COFFERDAM  
175' NAVIGATION PASS  
LOCK CLOSED

**LEGEND**  
MEAN VELOCITY IN FEET PER SECOND  
NOTE: SPOT VELOCITIES TAKEN ALONG TOE OF SLOPES NEAR BOTTOM AT 100 FT INTERVALS  
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

**SCALES**  
PROTOTYPE 400 0 400 800 FT  
MODEL 0 4 8 FT

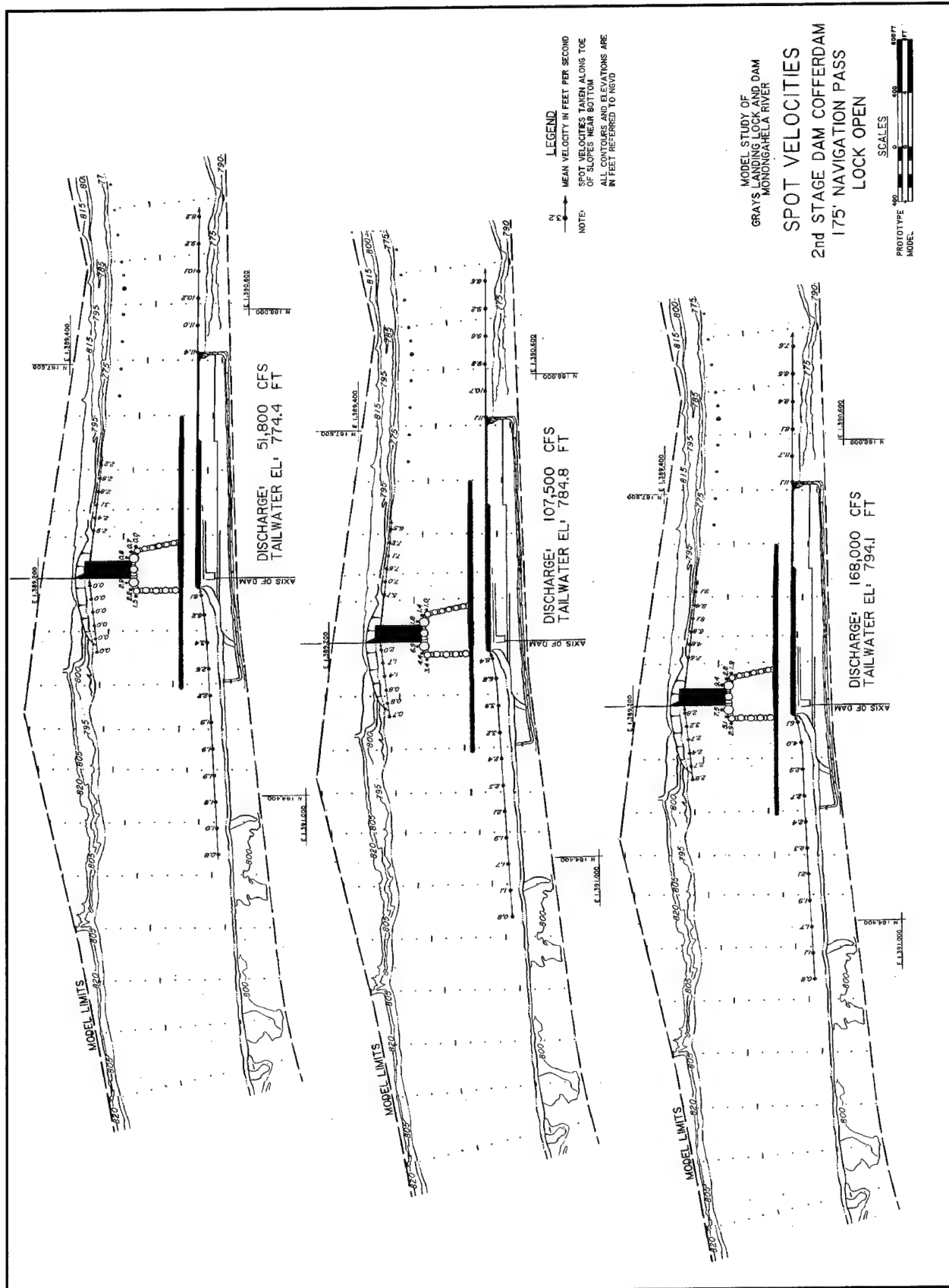
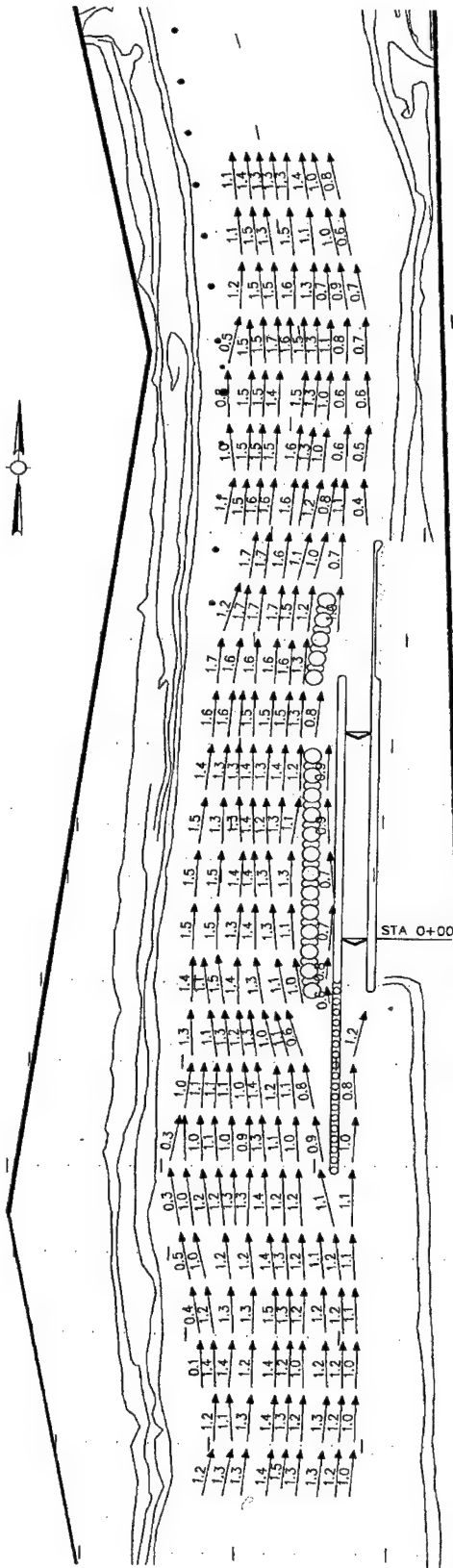


Plate 54



# LEGEND

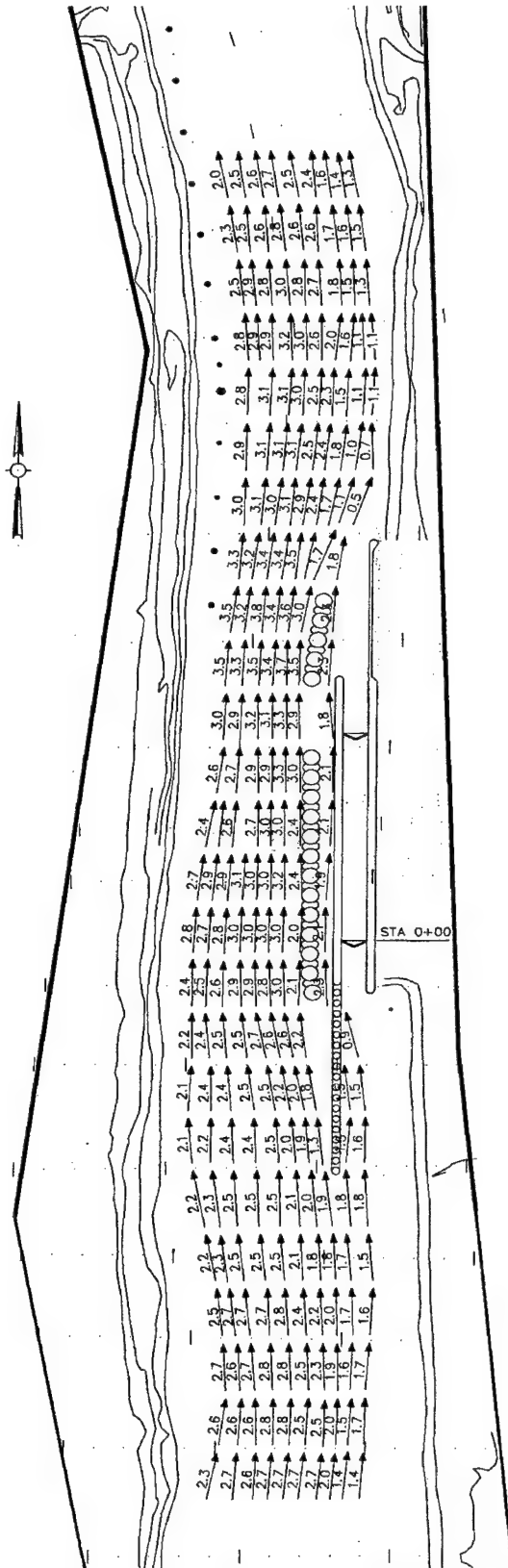
VELOCITY IN FEET PER SECOND  
VELOCITY LESS THAN 0.5 FEET  
PER SECOND

NOTE :  
VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED BARGE ( 9.0 FT )  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

## SCALES



VELOCITIES AND  
CURRENT DIRECTIONS  
CONSTRUCTION SEQUENCE 1ST STAGE  
DISCHARGE: 6,000 CFS  
TAILWATER EL: 763.9 FT



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

VELOCITIES AND  
CURRENT DIRECTIONS

FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - TEST 1

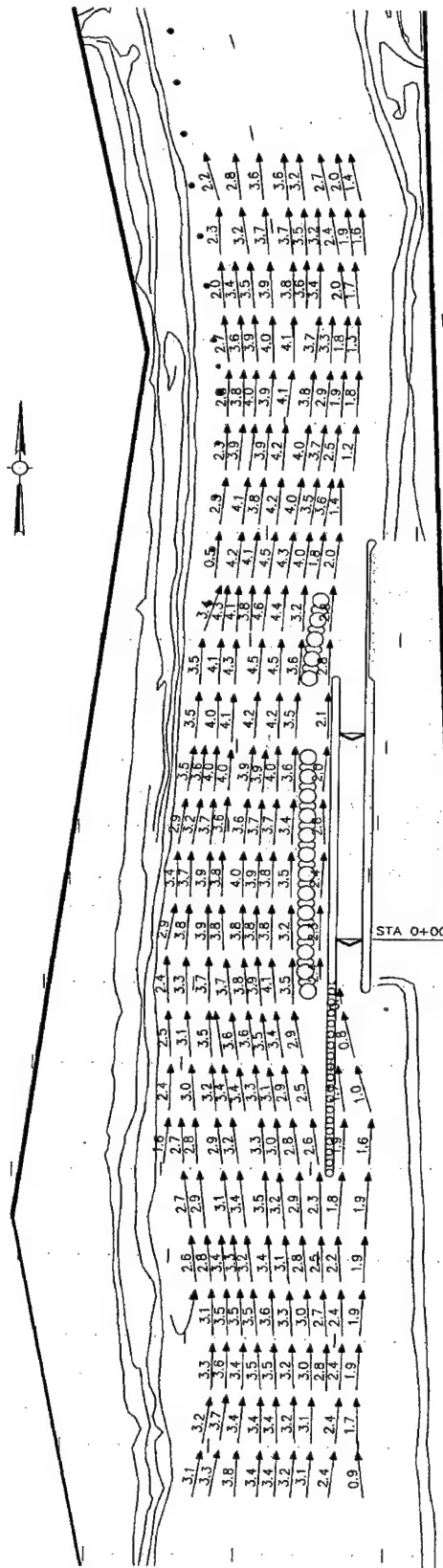
DISCHARGE: 12,000 CFS  
TAIL WATER EL: 765.0 FT



LEGEND

VELOCITY IN FEET PER SECOND  
VELOCITY LESS THAN 0.5 FEET  
PER SECOND

NOTE :  
VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED BARGE ( 9.0 FT )  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

VELOCITIES AND  
CURRENT DIRECTIONS

FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - TEST 1

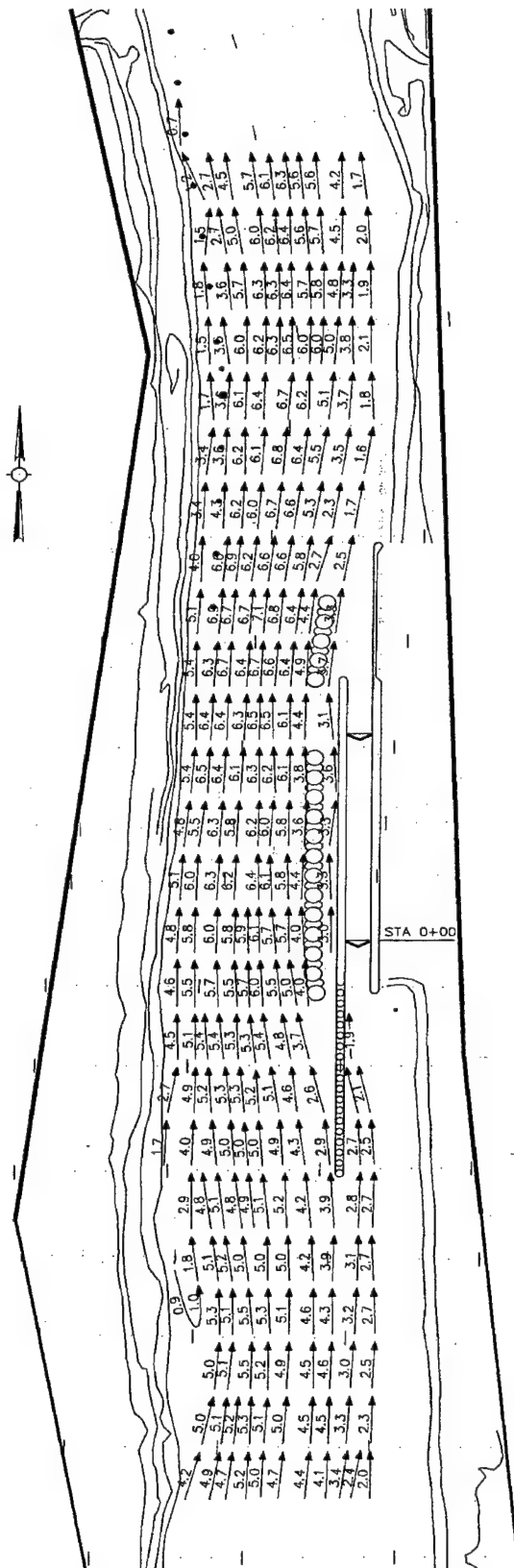
DISCHARGE: 25,000 CFS  
TAILWATER EL: 768.3 FT



LEGEND

— VELOCITY IN FEET PER SECOND  
— VELOCITY LESS THAN 0.5 FEET  
PER SECOND

NOTE: VELOCITIES AND CURRENT DIRECTION  
SHOWN WITH VELOCITIES REFERRED TO  
DRAFT OF LOADED BARGE (8.0 FT)  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

VELOCITIES AND  
CURRENT DIRECTIONS

FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - TEST 1

DISCHARGE: 51,800 CFS  
TAILWATER EL: 774.4 FT

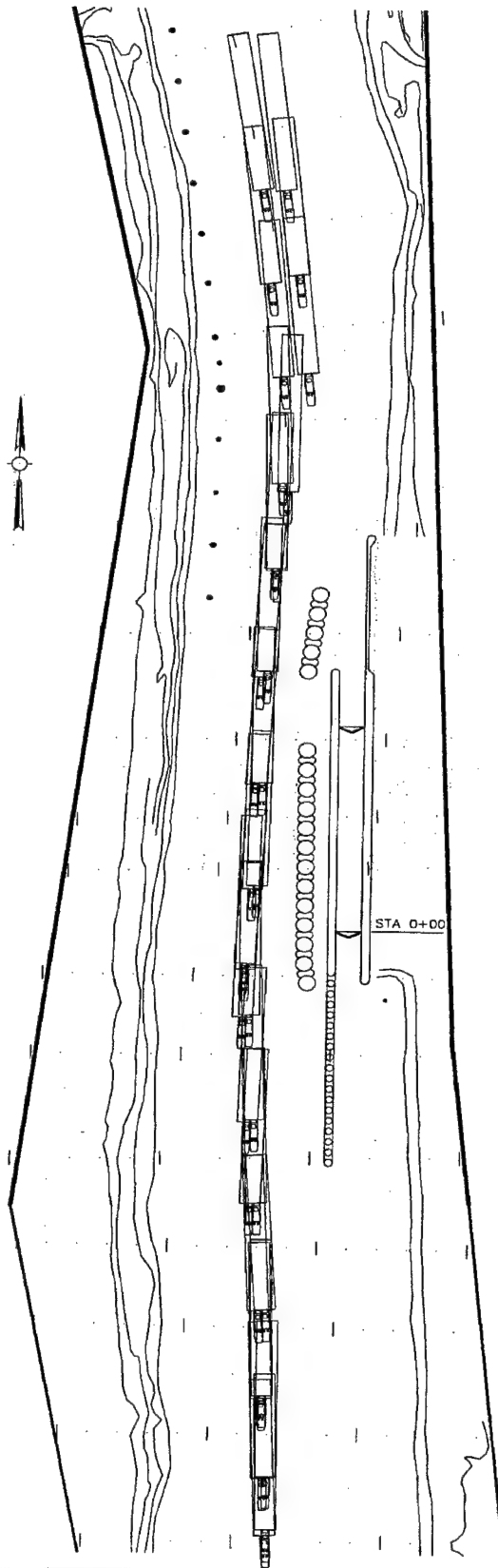


LEGEND

VELOCITY IN FEET PER SECOND  
VELOCITY LESS THAN 0.5 FEET  
PER SECOND

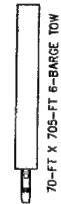
NOTE :  
VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED BARGE ( 9.0 FT )  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO CHD RIVER DATUM





MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
DOWNBOUND TOW PATHS  
MULTIPLE RUNS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - TEST 1  
DISCHARGE: 6,000 CFS  
TAILWATER EL: 763.9 FT

LEGEND



70-FT X 705-FT 6-BARGE TOW

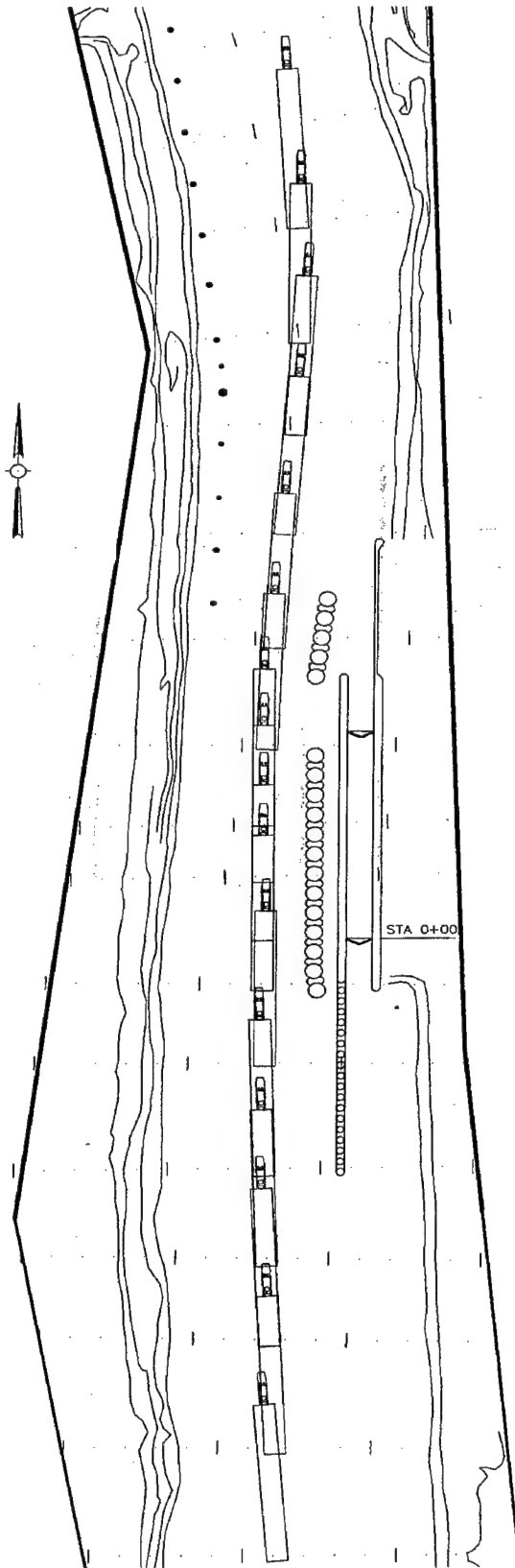
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



PROTOTYPE 0 500

MODEL 0 5

GRAY-075



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPBOUND TOW PATH  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - TEST 1  
DISCHARGE: 6,000 CFS  
TAIL WATER EL: 763.9 FT

LEGEND

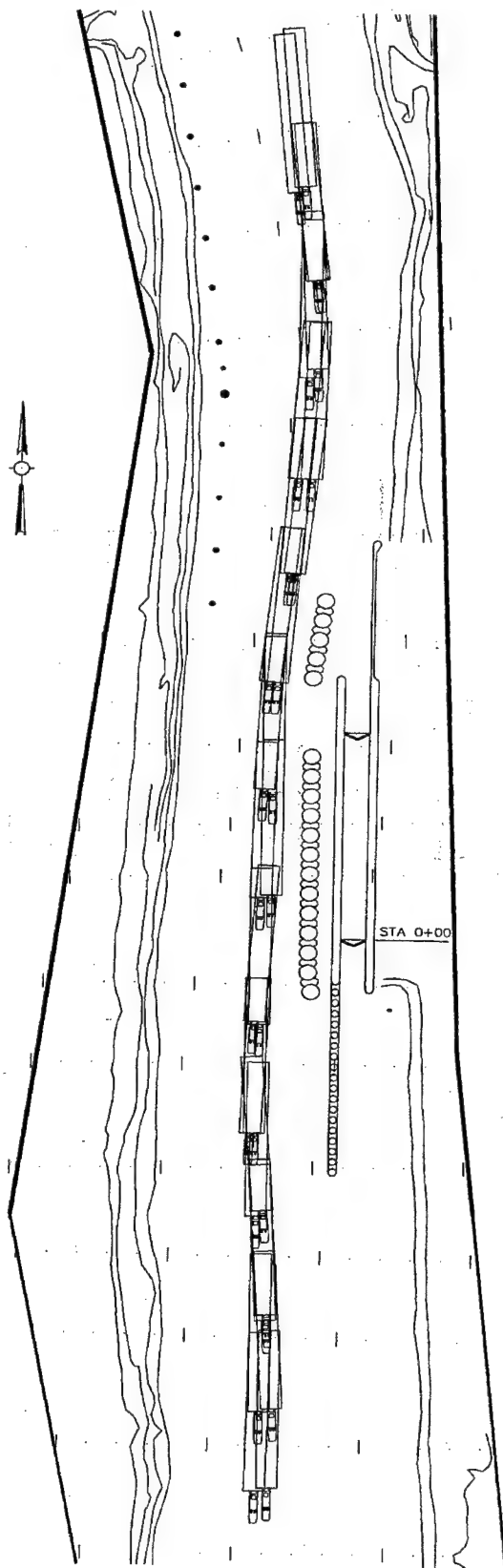


70-FT X 705-FT 6-BARGE TOW

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



GRAY-075



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

DOWNBOUND TOW PATHS

MULTIPLE RUNS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - TEST 1  
DISCHARGE: 51,800 CFS  
TAILWATER EL: 774.4 FT

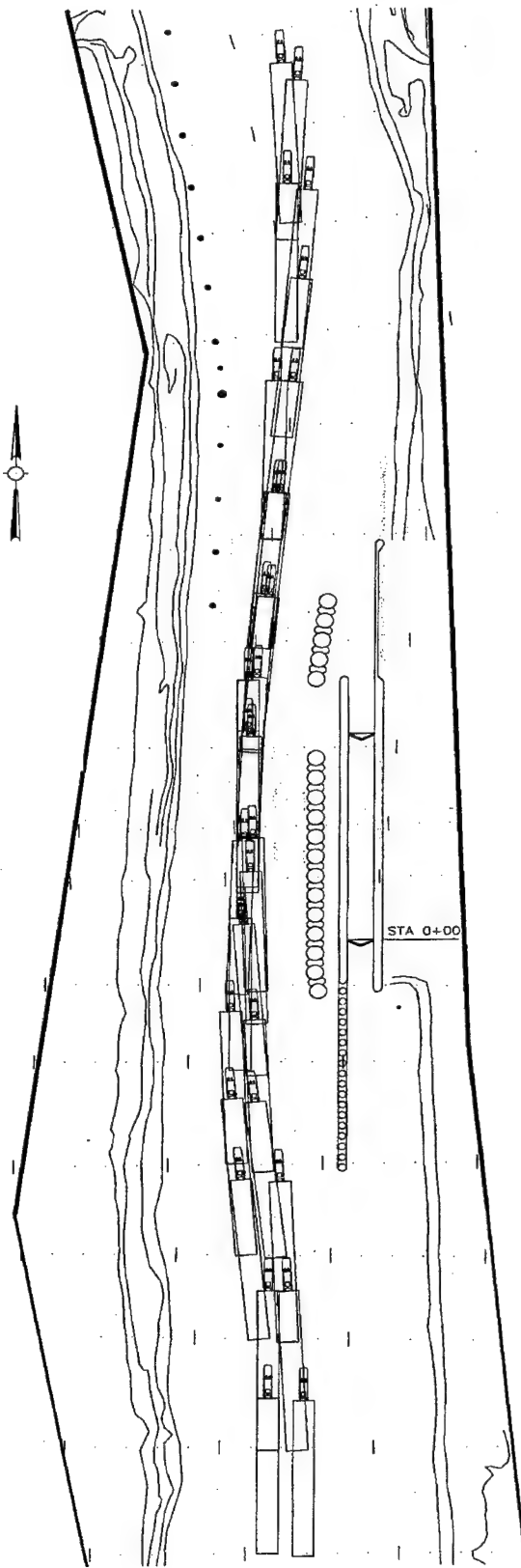
LEGEND



70-FT X 705-FT 6-BARGE TOW

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM





MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

UPBOUND TOW PATHS

MULTIPLE RUNS

FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - TEST 1

DISCHARGE: 51,800 CFS  
TAILWATER EL: 774.4 FT

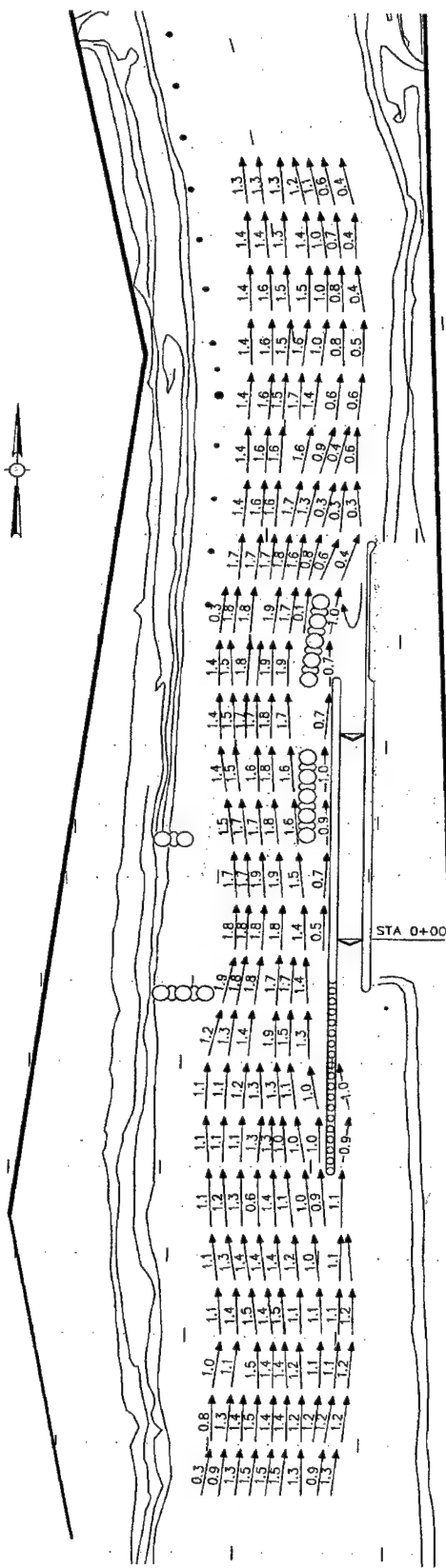
LEGEND

 70-FT X 705-FT 6-BARGE TOW

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

SCALES





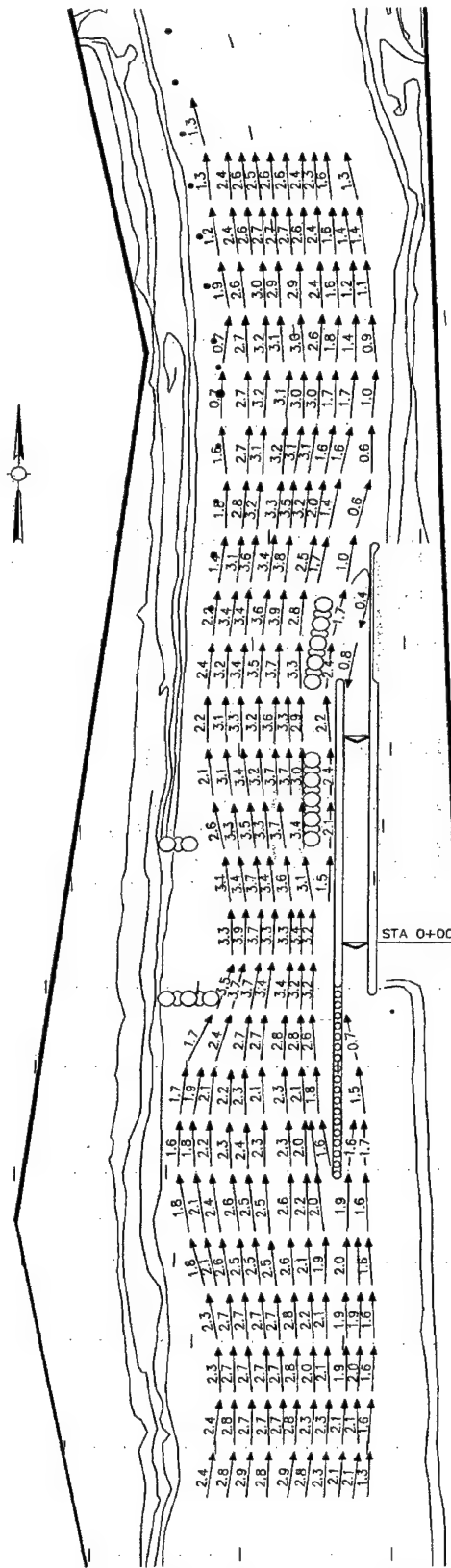
MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
VELOCITIES AND  
CURRENT DIRECTIONS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - TEST 2  
DISCHARGE: 6,000 CFS  
TAILWATER EL: 763.9 FT



LEGEND

VELOCITY IN FEET PER SECOND  
VELOCITY LESS THAN 0.5 FEET  
PER SECOND

NOTE: VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED BARGE ( 8.0 FT )  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

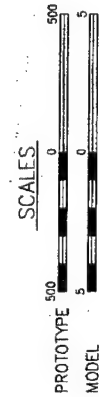


MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

VELOCITIES AND  
CURRENT DIRECTIONS

FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - TEST 2

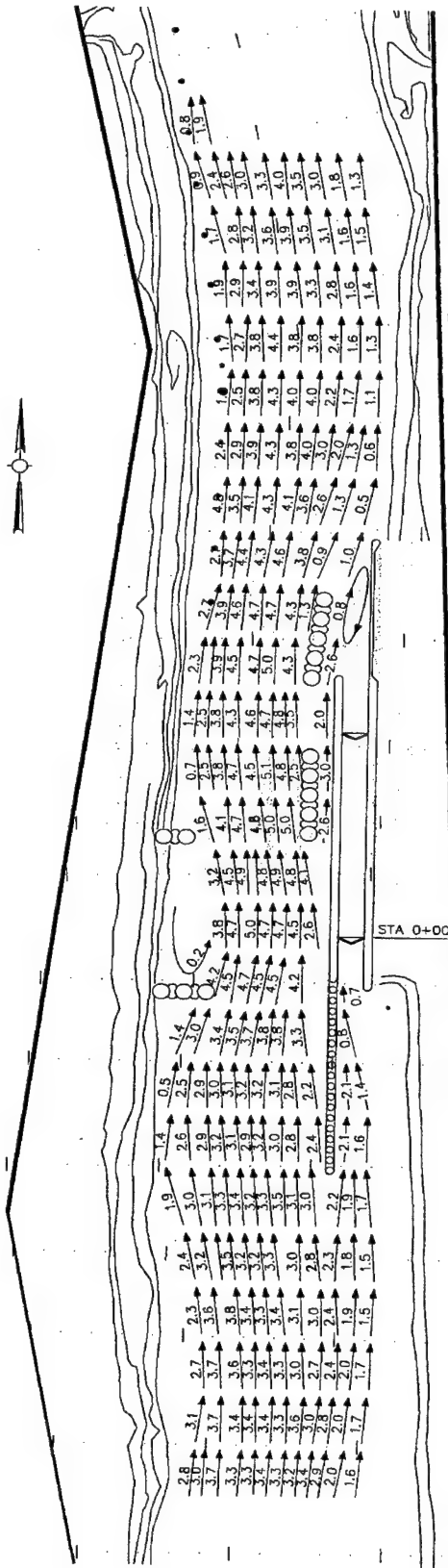
DISCHARGE: 12,000 CFS  
TAILWATER EL: 765.0 FT



LEGEND

VELOCITY IN FEET PER SECOND  
VELOCITY LESS THAN 0.5 FEET  
PER SECOND

NOTE: VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED BARGE (3.0 FT)  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



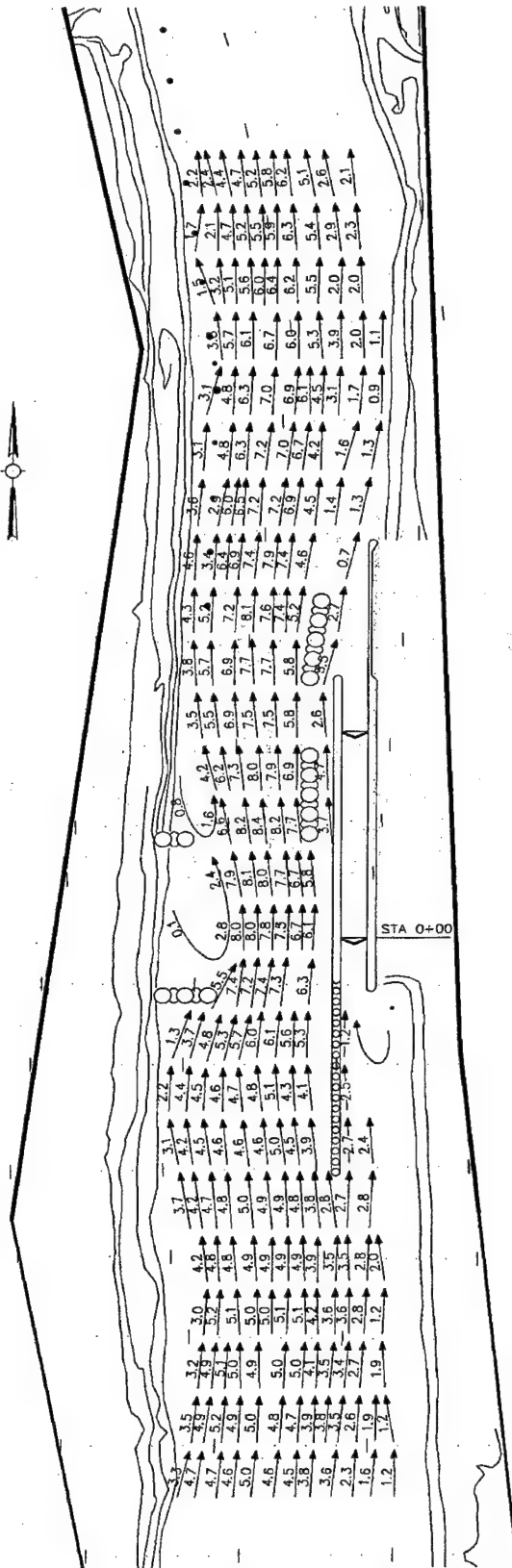
MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
CURRENT DIRECTIONS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - TEST 2  
DISCHARGE: 25,000 CFS  
TAIL WATER EL: 768.3 FT



# LEGEND

VELOCITY IN FEET PER SECOND  
VELOCITY LESS THAN 0.5 FEET  
PER SECOND

NOTE: VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED GAGE (9.0 FT)  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

VELOCITIES AND  
CURRENT DIRECTIONS

FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - TEST 2

DISCHARGE: 51,800 CFS  
TAILWATER EL: 774.4 FT

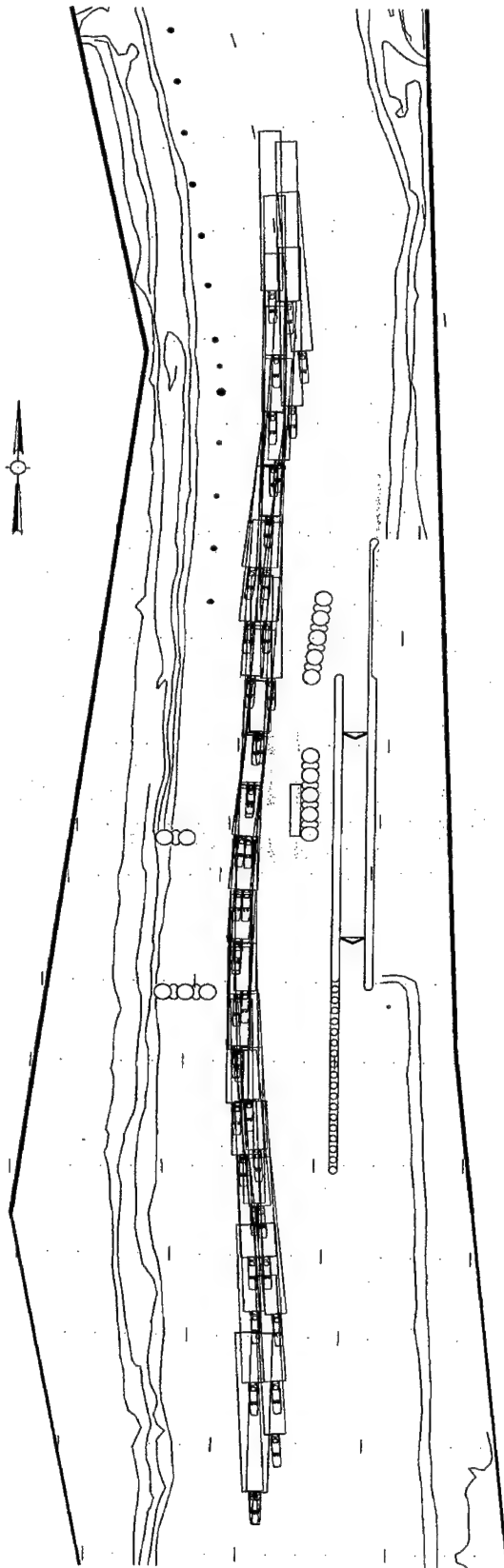


LEGEND

→ VELOCITY IN FEET PER SECOND  
→ VELOCITY LESS THAN 0.5 FEET  
→ PER SECOND

NOTE: VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED BARGE (9.0 FT)  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM





MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

DOWNBOUND TOW PATHS

MULTIPLE RUNS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 2  
DISCHARGE: 6,000 CFS  
TAILWATER EL: 763.9 FT

LEGEND



70-FT X 705-FT 6-BARGE TOW

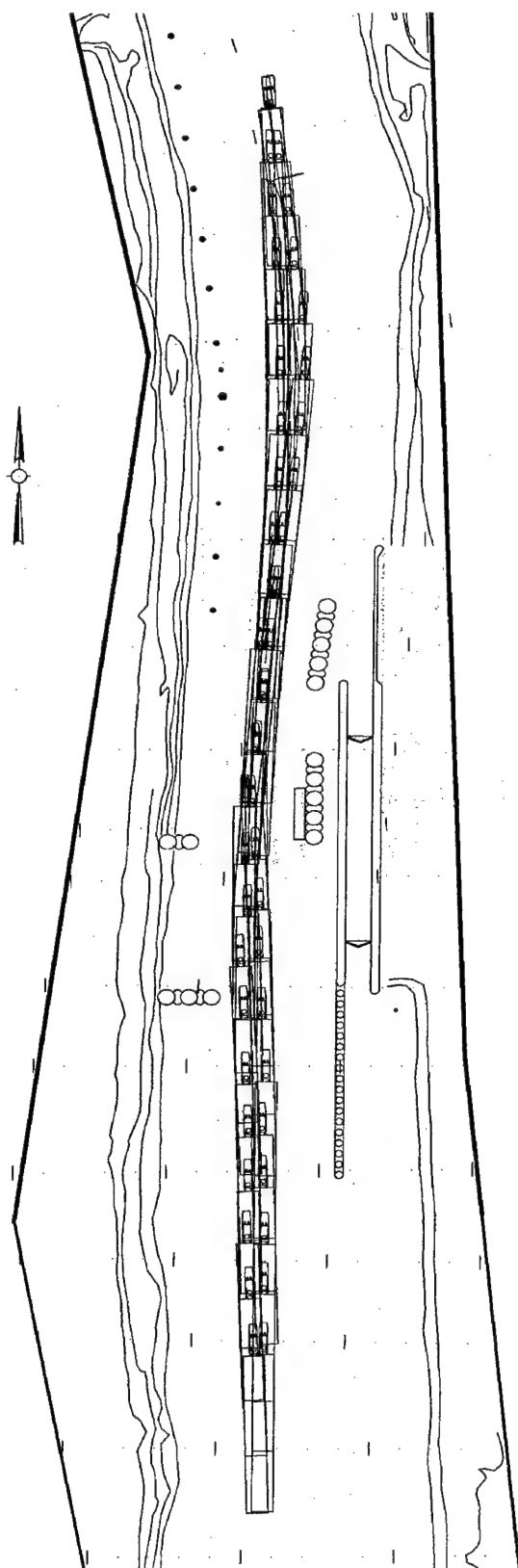
35 FT X 185 FT WORK BARGE  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

SCALES



PROTOTYPE 500 0 500

MODEL 5 0 5

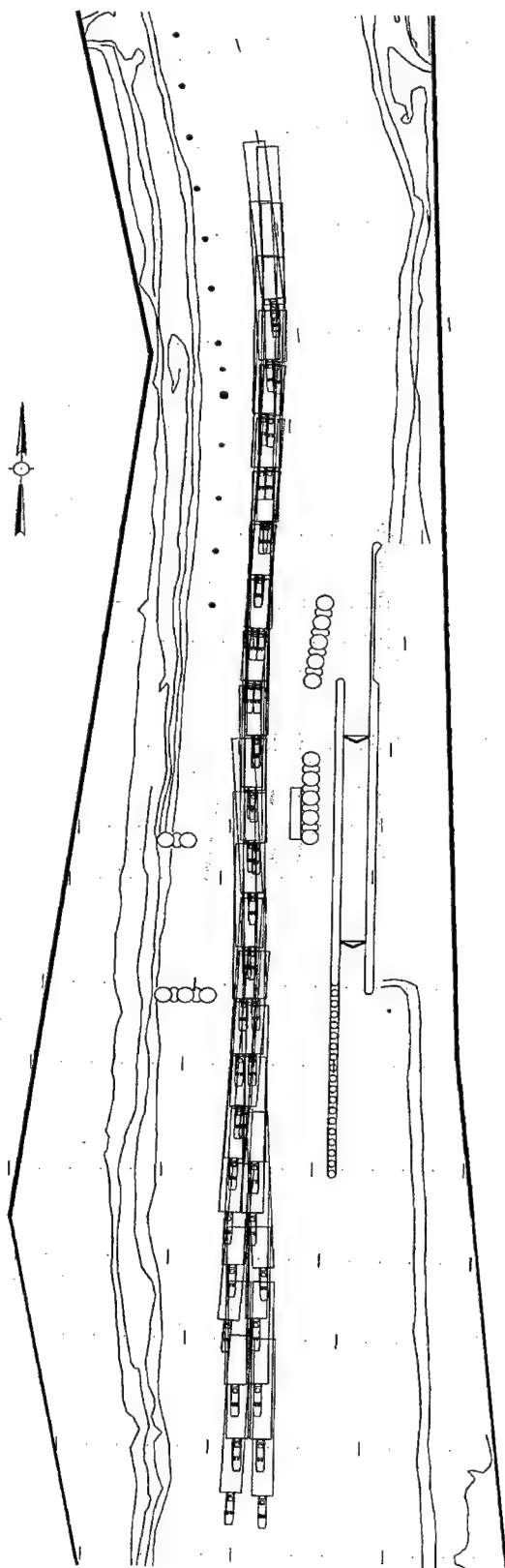


MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPBOUND TOW PATHS  
MULTIPLE RUNS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 2  
DISCHARGE: 6,000 CFS  
TAILWATER EL: 763.9 FT

LEGEND

- 70-FT X 705-FT 6-BARGE TOW
- 35 FT X 185 FT WORK BARGE
- ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM





MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

DOWNBOUND TOW PATHS

MULTIPLE RUNS

FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 2

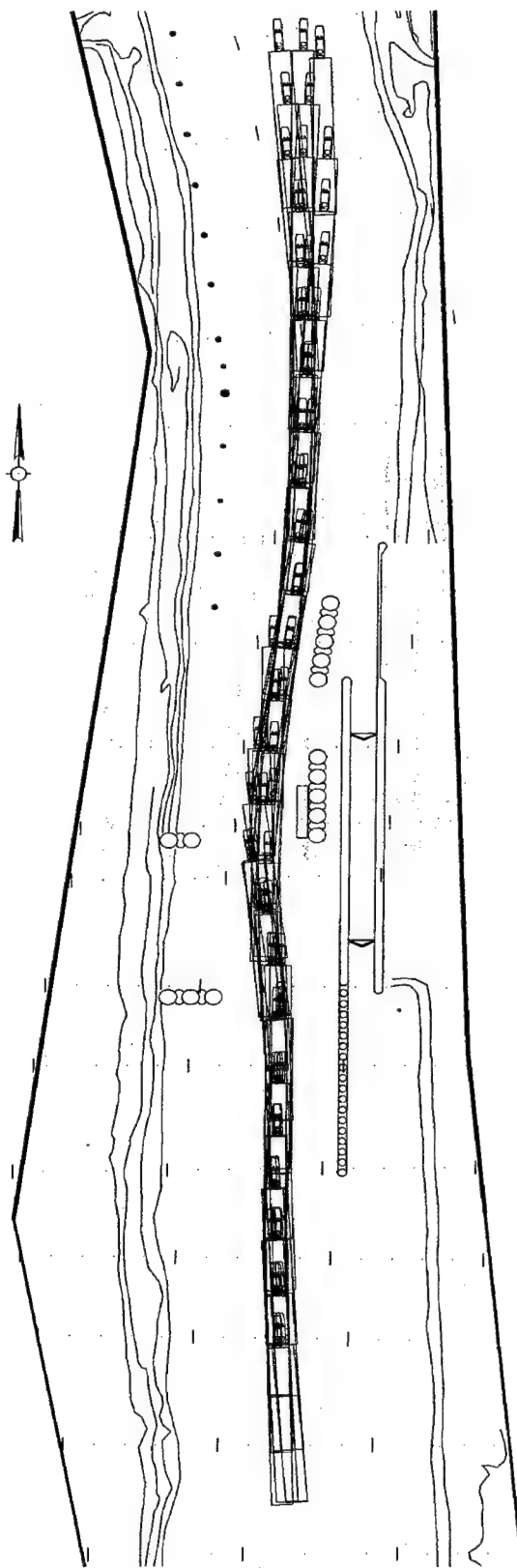
DISCHARGE: 12,000 CFS  
TAILWATER EL: 765.0 FT

LEGEND

70-FT X 705-FT 6-BARGE TOW  
35 FT X 195 FT WORK BARGE  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



GRAY-068



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPBOUND TOW PATHS  
MULTIPLE RUNS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 2  
DISCHARGE: 12,000 CFS  
TAILWATER EL: 765.0 FT

LEGEND

- 70'-FT X 705'-FT 6-BARGE TOW
- 35 FT X 195 FT WORK BARGE
- ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

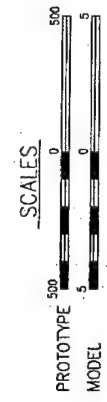
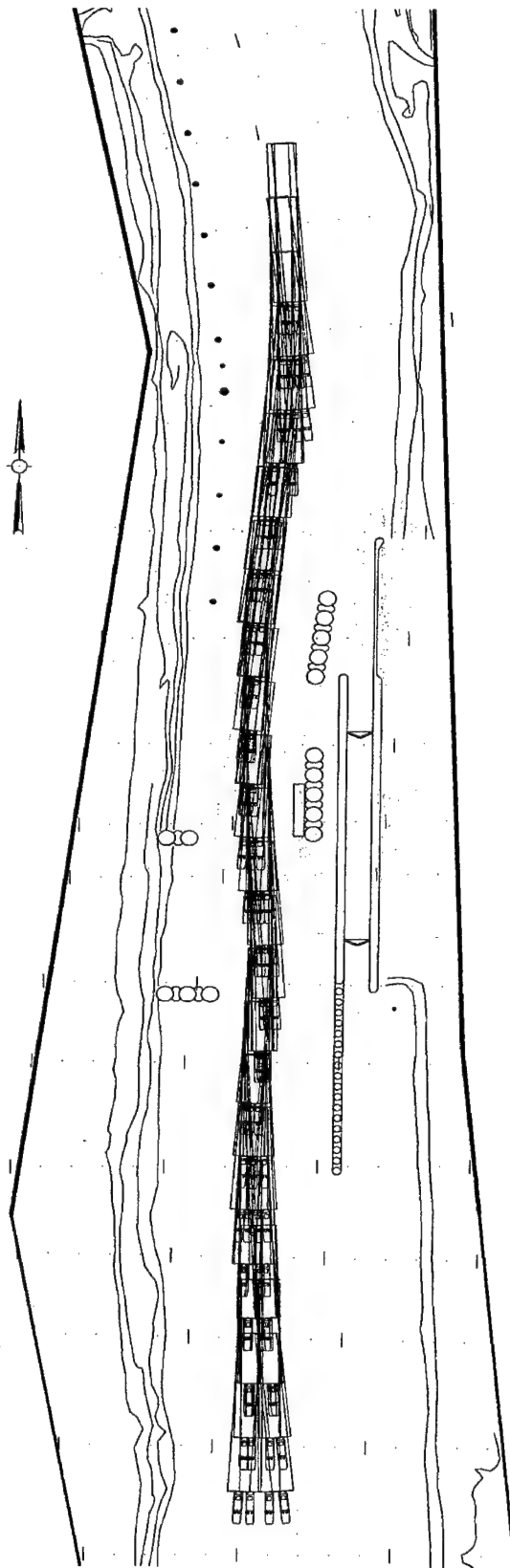


Plate 70



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

DOWNBOUND TOW PATHS

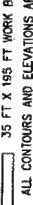
MULTIPLE RUNS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 2

DISCHARGE: 25,000 CFS  
TAILWATER EL: 768.3 FT

LEGEND



70-FT X 705-FT 6-BARGE TOW



35 FT X 185 FT WORK BARGE

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



SCALES

PROTOTYPE

MODEL

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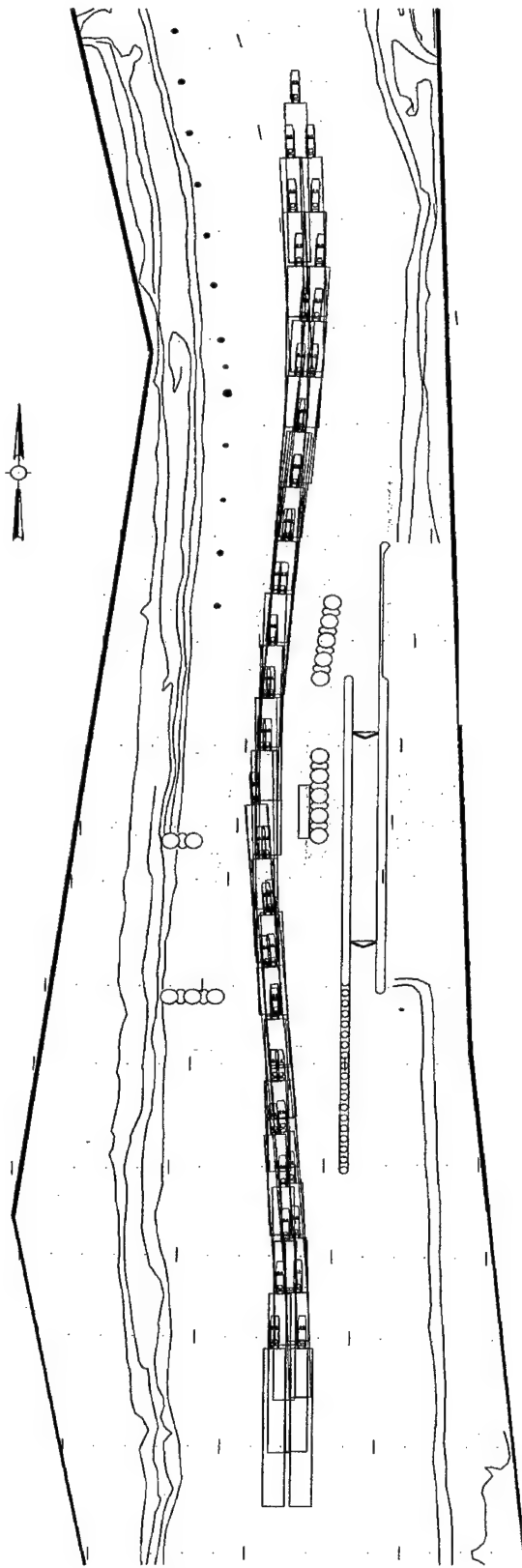
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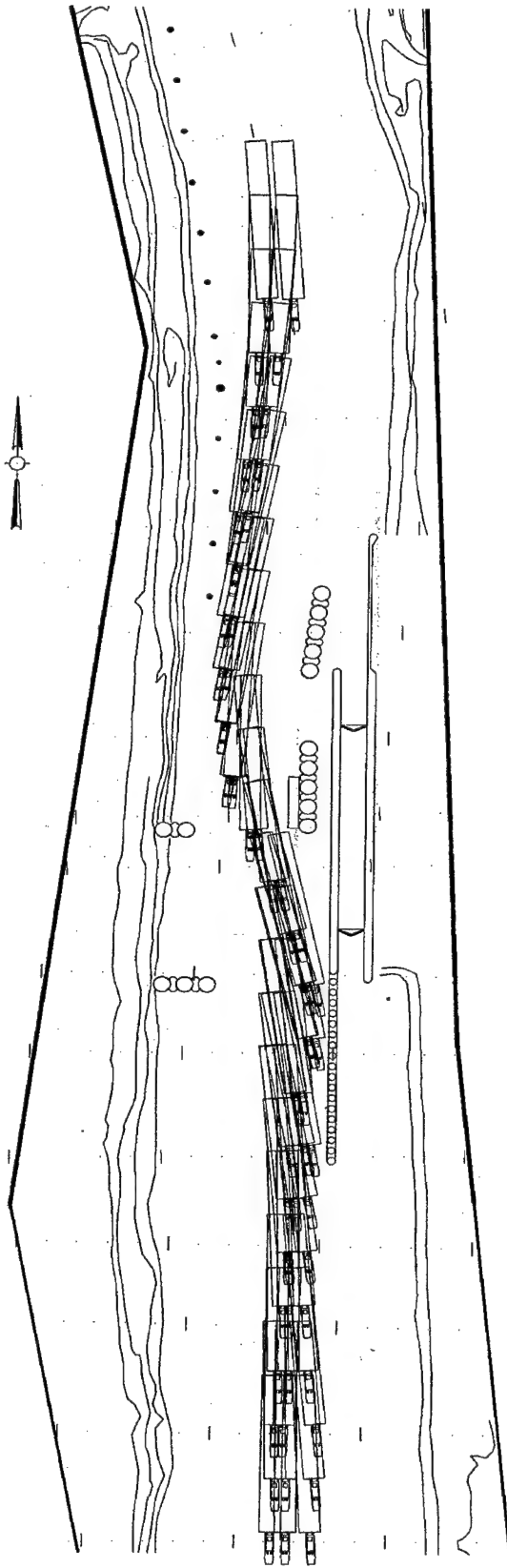
MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPBOUND TOW PATHS  
MULTIPLE RUNS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 2  
DISCHARGE: 25,000 CFS  
TAILWATER EL: 768.3 FT

LEGEND

- 70-FT X 705-FT 5-BARGE TOW
- 35 FT X 195 FT WORK BARGE
- ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

SCALES

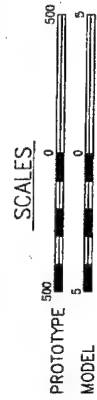


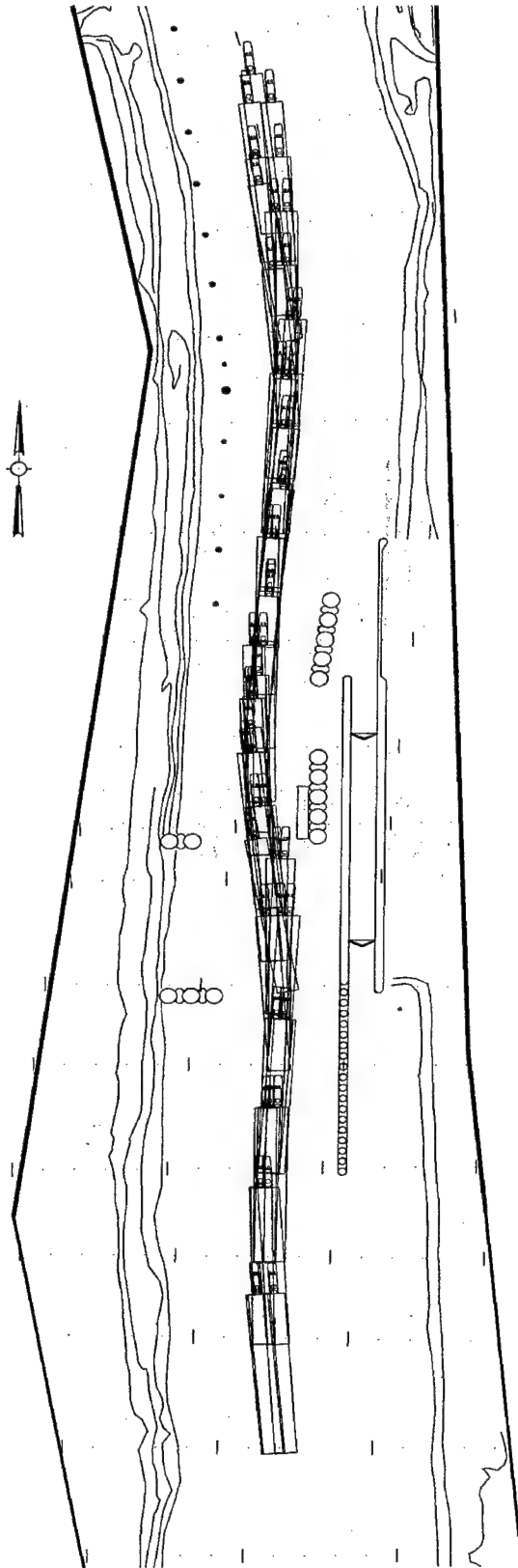


MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
DOWNBOUND TOW PATHS  
MULTIPLE RUNS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 2  
DISCHARGE: 51,800 CFS  
TAIL WATER EL: 774.4 FT

LEGEND

- 70-FT X 705-FT 6-BARGE TOW
- 35-FT X 195-FT WORK BARGE
- ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM





MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPROUND TOW PATHS  
MULTIPLE RUNS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 2  
DISCHARGE: 51,800 CFS  
TAILWATER EL: 774.4 FT

LEGEND

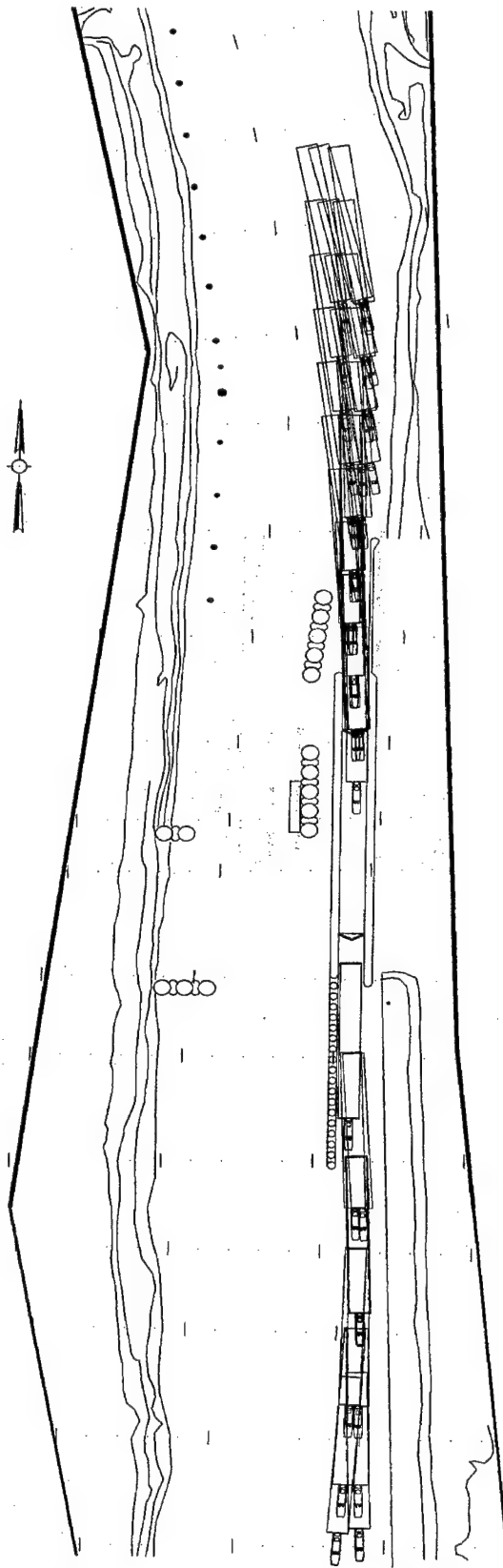
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35 FT X 195 FT WORK BARGE  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

SCALES





GRAY-080



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

DOWNBOUND TOW PATHS

MULTIPLE RUNS THROUGH LOCK  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 2

DISCHARGE: 51,800 CFS  
TAILWATER EL: 774.4 FT

LEGEND



70-FT X 705-FT 6-BARGE TOW



35-FT X 195-FT WORK BARGE  
ALL CONTIGUOUS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



SCALES:

PROTOTYPE

MODEL

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0

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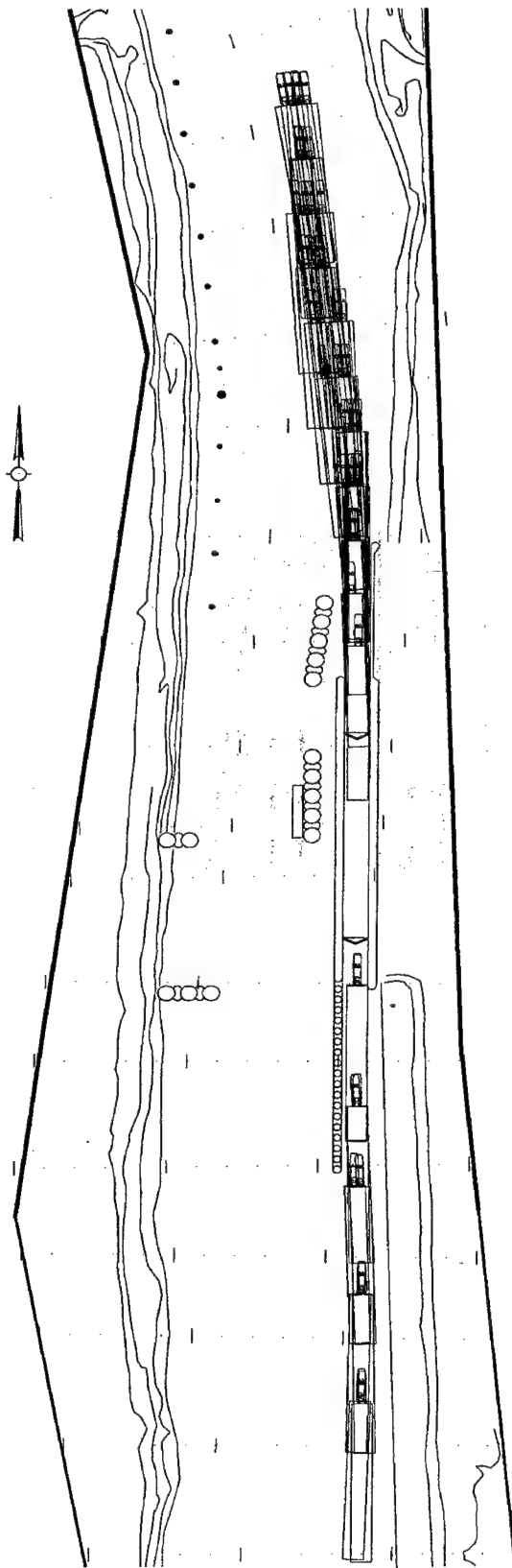
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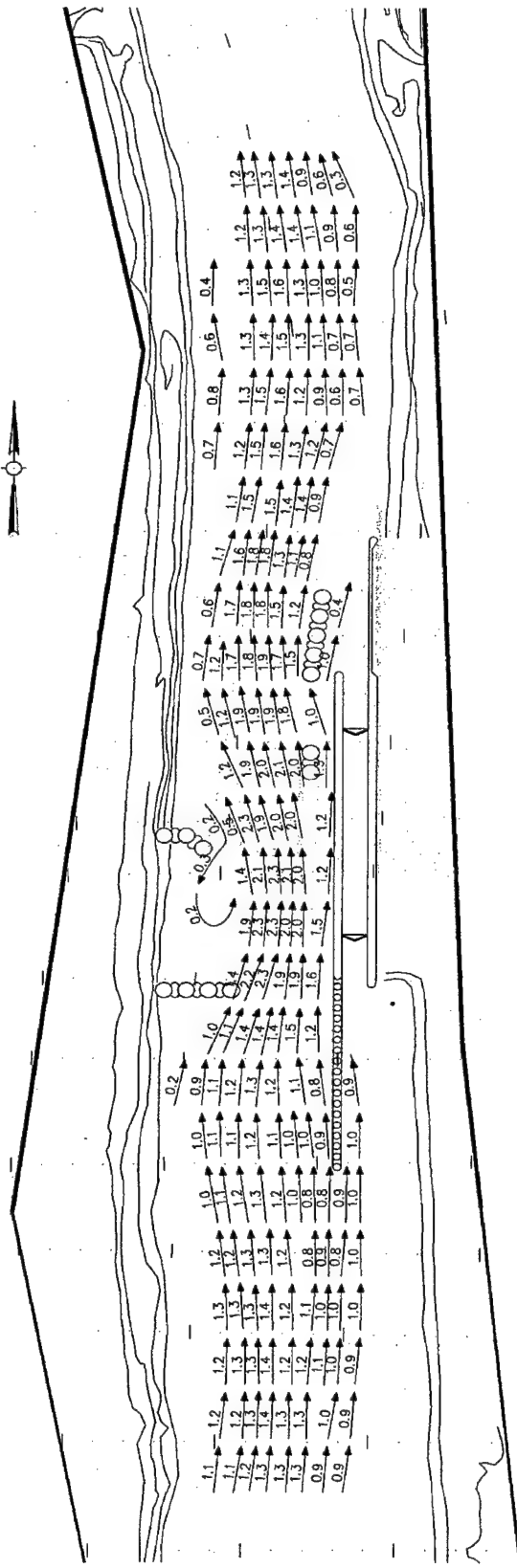


MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPBOUND TOW PATHS  
MULTIPLE RUNS THROUGH LOCK  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 2  
DISCHARGE: 51,800 CFS  
TAILWATER EL: 774.4 FT



LEGEND

- 70'-FT X 705'-FT 6-BARGE TOW
- 35 FT X 195 FT WORK BARGE
- ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO OHIO RIVER DATUM

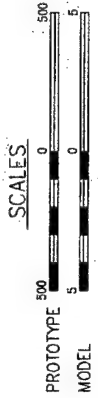


MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

VELOCITIES AND  
CURRENT DIRECTIONS

1ST STAGE OF DAM COFFERDAM - PHASE 3

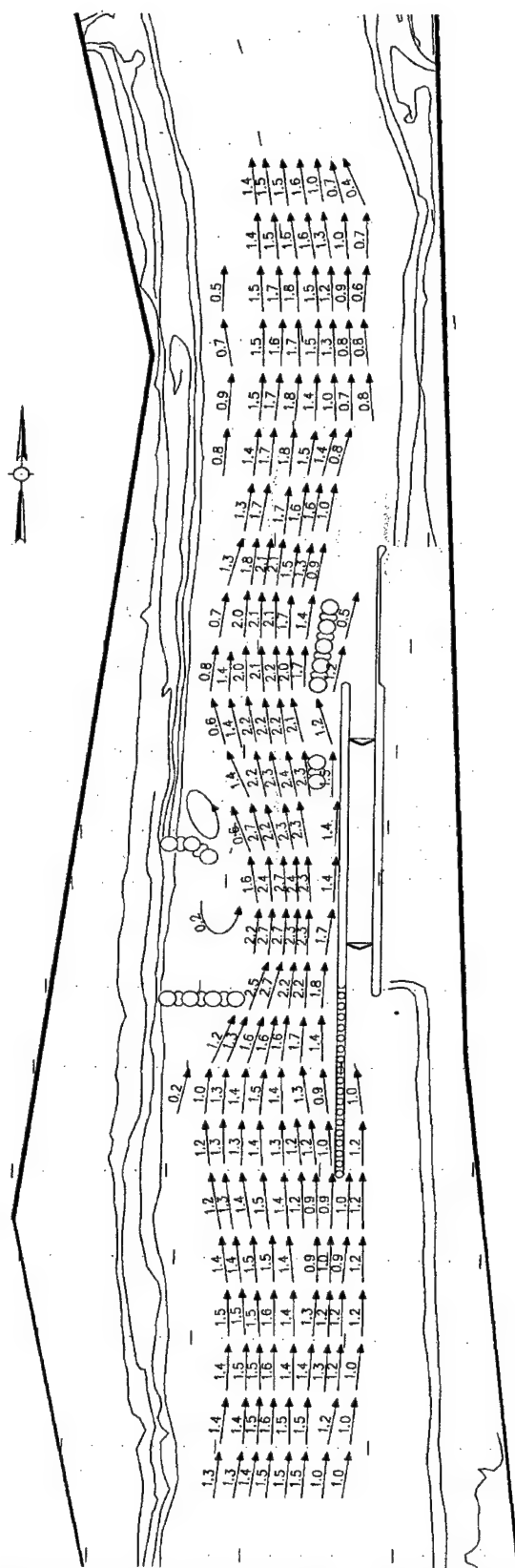
DISCHARGE: 6000 CFS  
TAILWATER EL: 63.9 FT



LEGEND

VELOCITY IN FEET PER SECOND  
VELOCITY LESS THAN 0.5 FEET  
PER SECOND

NOTE :  
VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED BARGE ( 9.0 FT )  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

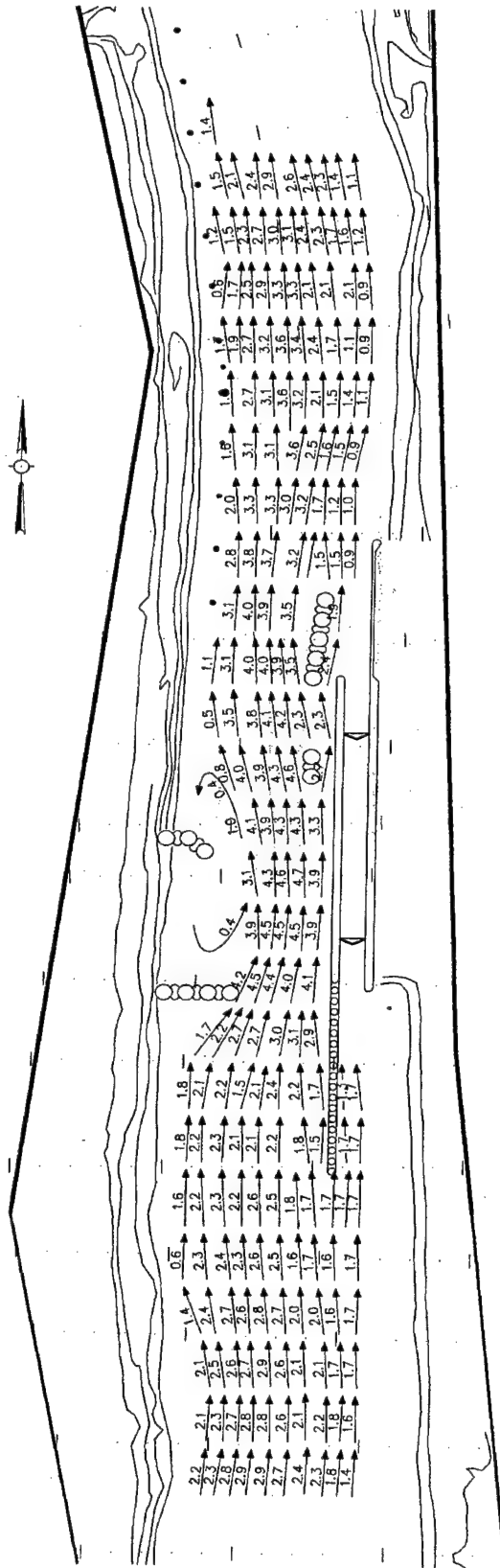


MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
VELOCITIES AND  
CURRENT DIRECTIONS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 3  
DISCHARGE: 9,000 CFS  
TAILWATER EL: 764.5 FT

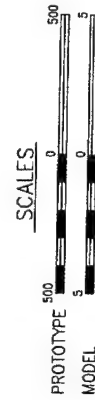
LEGEND  
— 1.5 — VELOCITY IN FEET PER SECOND  
— 1.0 — VELOCITIES LESS THAN 0.5 FEET  
PER SECOND

NOTE: VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED BARGE ( 9.0 FT )  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO GMD RIVER DATUM





MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
VELOCITIES AND  
CURRENT DIRECTIONS  
FIRST STAGE OF DAM OFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 3  
DISCHARGE: 12,000 CFS  
TAILWATER EL: 765.0 FT

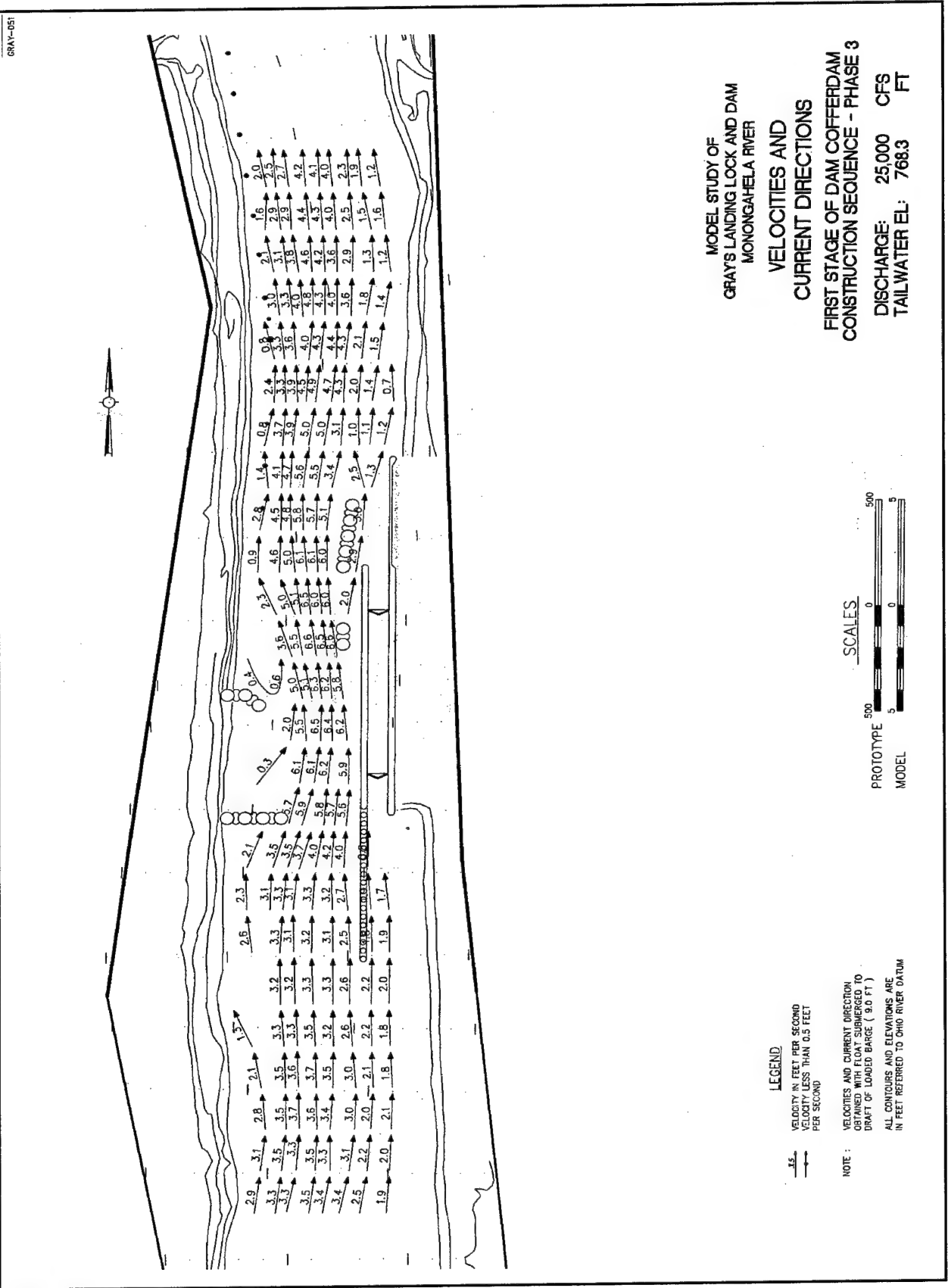


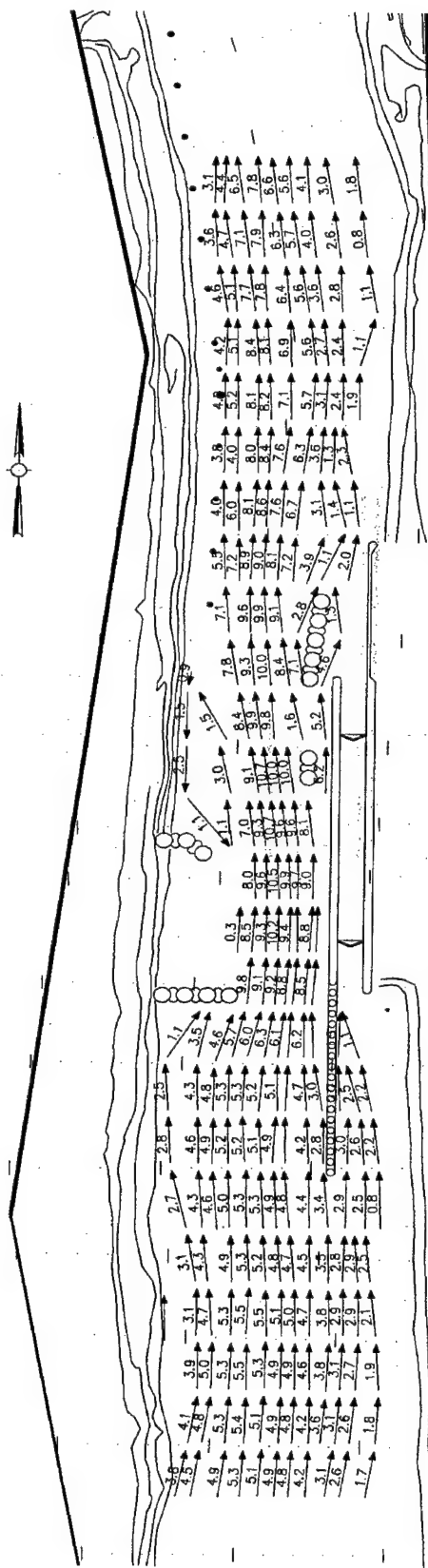
LEGEND

VELOCITY IN FEET PER SECOND  
VELOCITY LESS THAN 0.5 FEET  
PER SECOND

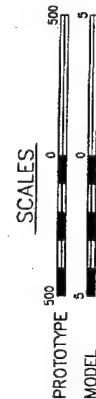
NOTE :  
VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
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ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

Plate 80





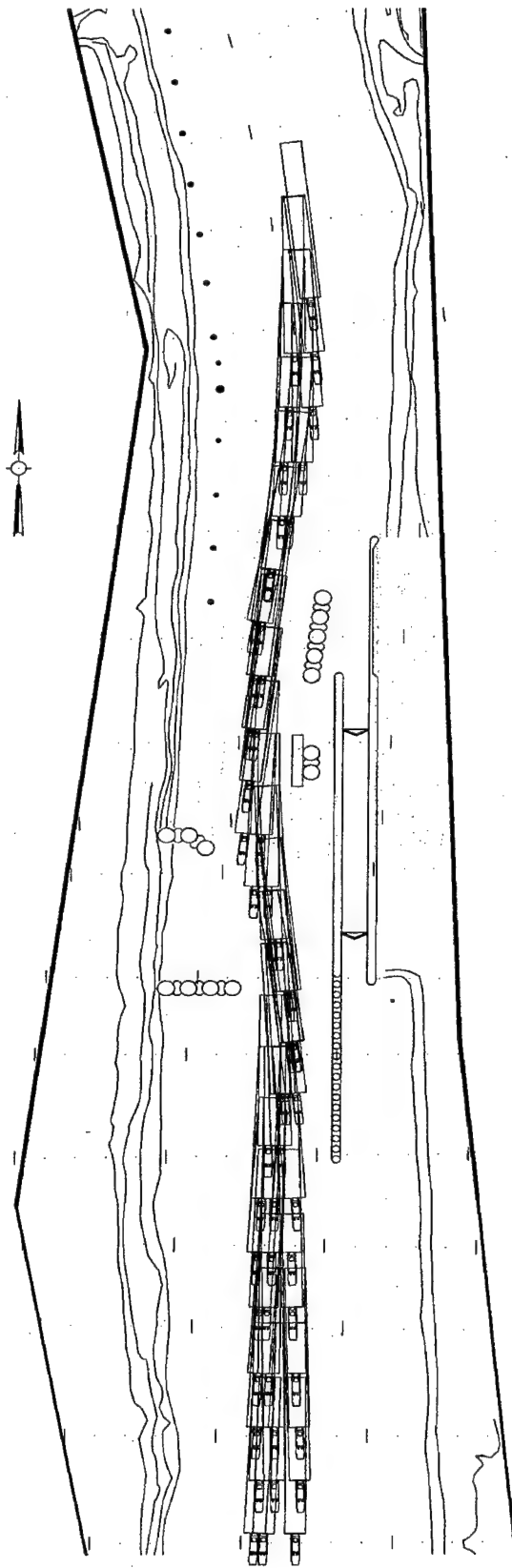
MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
VELOCITIES AND  
CURRENT DIRECTIONS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 3  
DISCHARGE: 51,800 CFS  
TAILWATER EL: 774.4 FT



**LEGEND**

VELOCITY IN FEET PER SECOND  
VELOCITY LESS THAN 0.5 FEET  
PER SECOND

NOTE :  
VELOCITIES AND CURRENT DIRECTION  
OBTAINED WITH FLOAT SUBMERGED TO  
DRAFT OF LOADED BARGE ( 9.0 FT )  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

DOWNBOUND TOW PATHS

MULTIPLE RUNS

FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 3

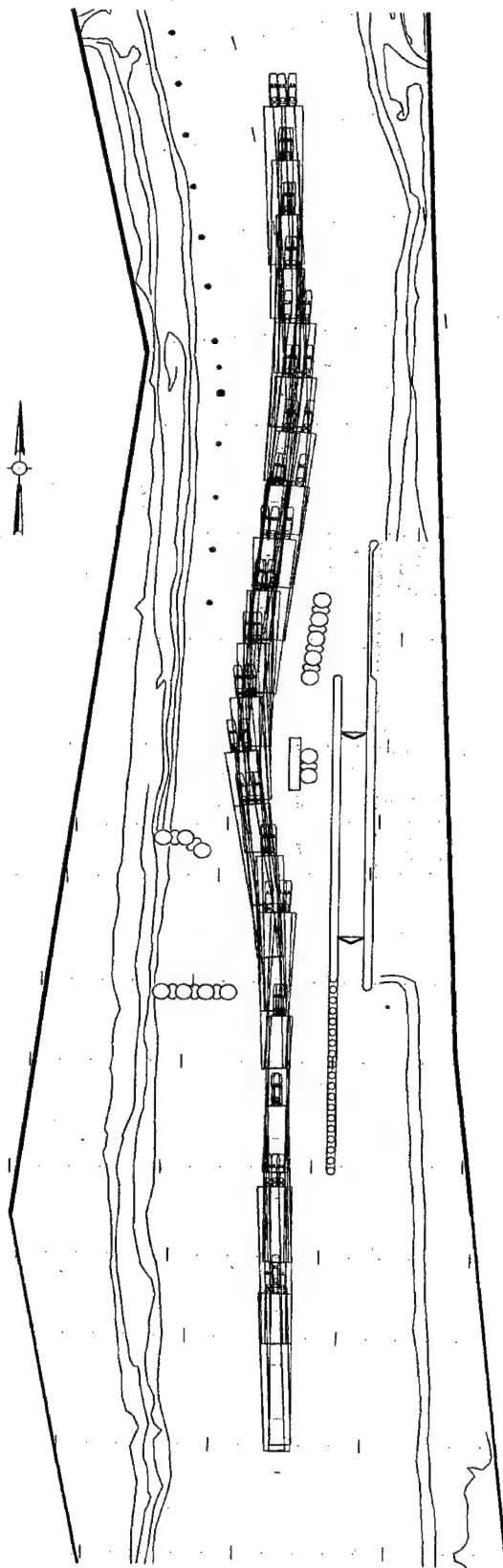
DISCHARGE: 6,000 CFS  
TAILWATER EL: 7639 FT

LEGEND

70-FT X 705-FT 6-BARGE TOW  
35 FT X 195 FT WORK BARGE  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM







MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

UPBOUND TOW PATHS

MULTIPLE RUNS

FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 3

DISCHARGE: 6,000 CFS  
TAILWATER EL: 763.9 FT

LEGEND

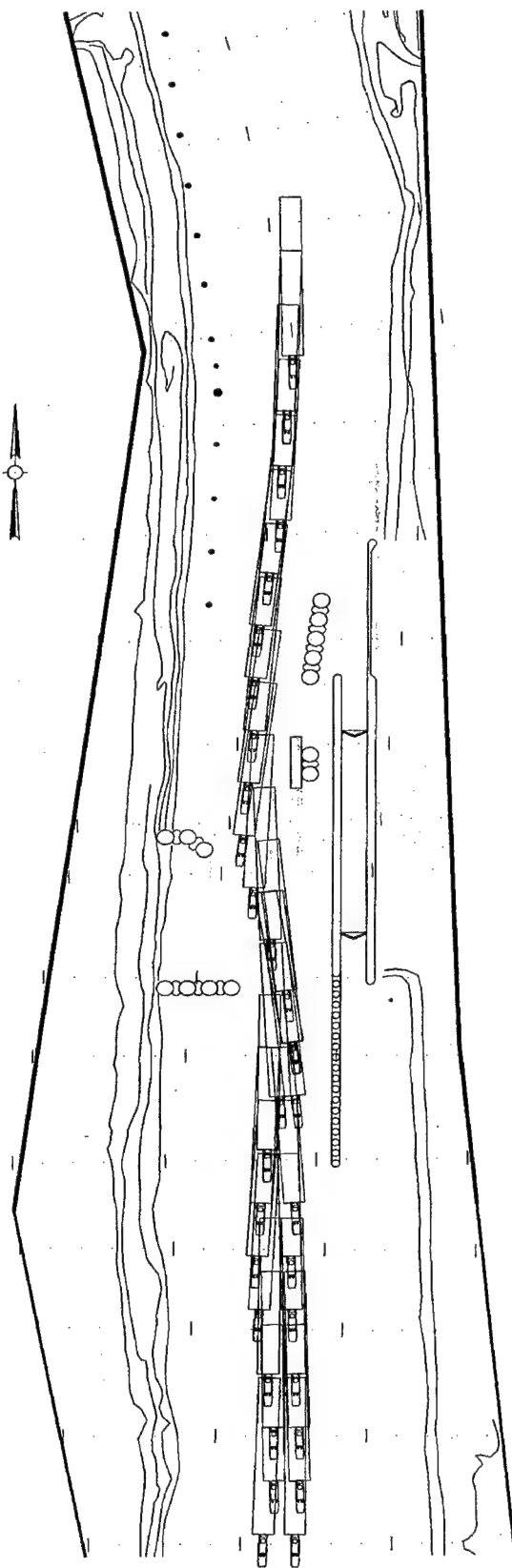
70-FT X 705-FT B-BARGE TOW

35 FT X 185 FT WORK BARGE

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO GING RIVER DATUM

SCALES





MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

DOWNBOUND TOW PATHS

MULTIPLE RUNS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 3

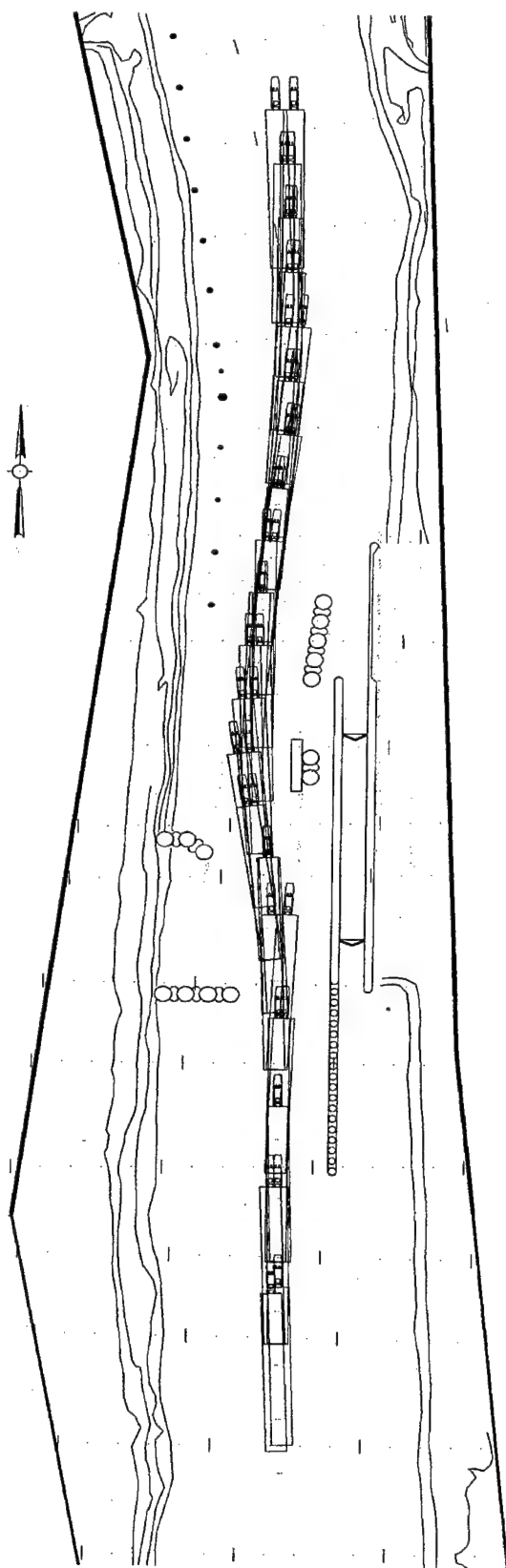
DISCHARGE: 9,000 CFS  
TAILWATER EL: 764.5 FT

LEGEND

70-FT X 705-FT 6-BARGE TOW

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM





MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPBOUND TOW PATHS  
MULTIPLE RUNS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 3  
DISCHARGE: 9,000 CFS  
TAILWATER EL: 764.5 FT

LEGEND



70-FT X 705-FT 6-BARGE TOW

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

SCALES



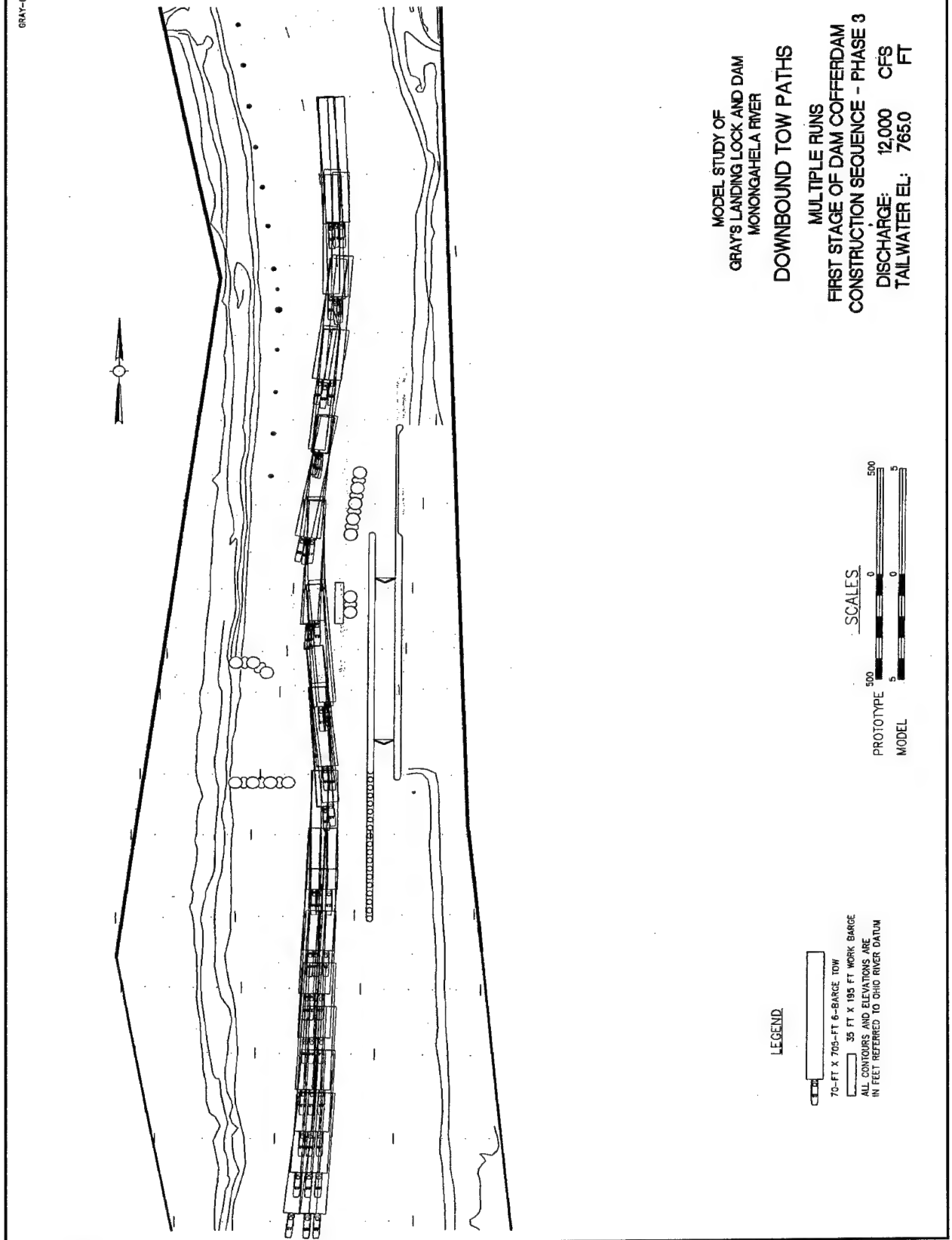
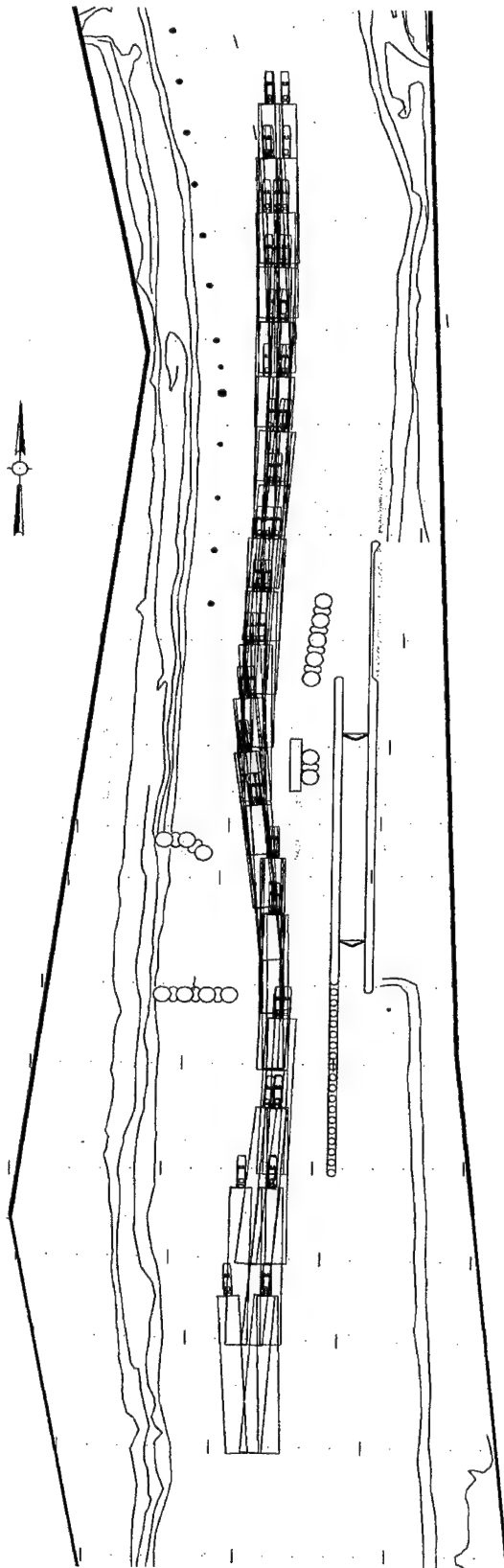


Plate 86

GRAY-050

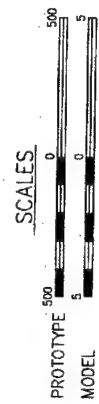


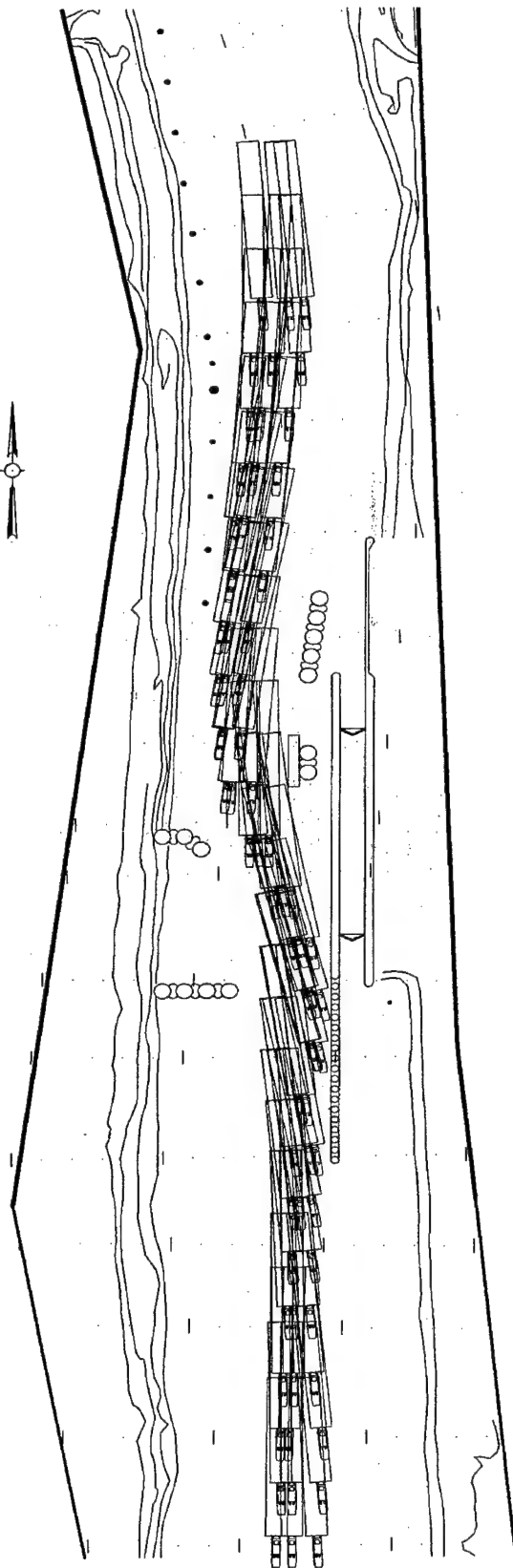
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GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPBOUND TOW PATHS  
MULTIPLE RUNS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 3  
DISCHARGE: 12,000 CFS  
TAILWATER EL: 765.0 FT

LEGEND

70-FT X 705-FT 6-BARGE TOW

35-FT X 195-FT WORK BARGE  
ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM





MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

DOWNBOUND TOW PATHS


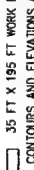
MULTIPLE RUNS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 3

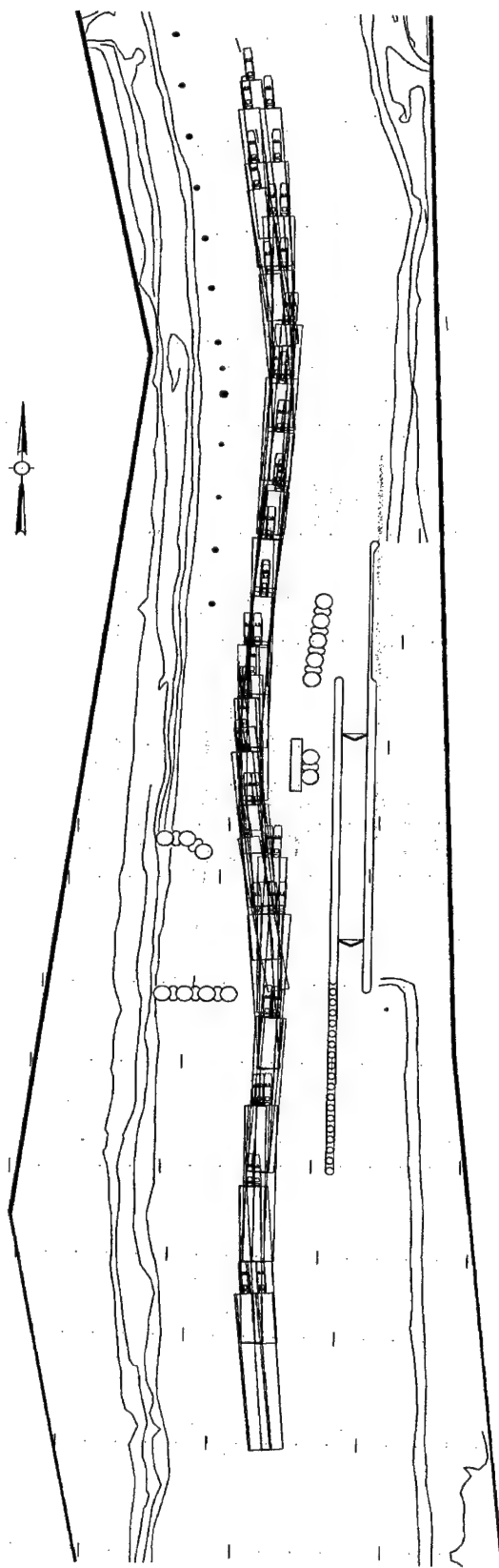
DISCHARGE: 25,000 CFS  
TAILWATER EL: 768.3 FT

SCALES



LEGEND

-  70-FT X 705-FT 6-BARGE TOW
-  35 FT X 195 FT WORK BARGE
- ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

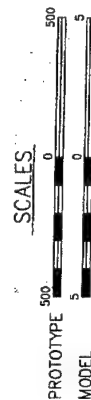


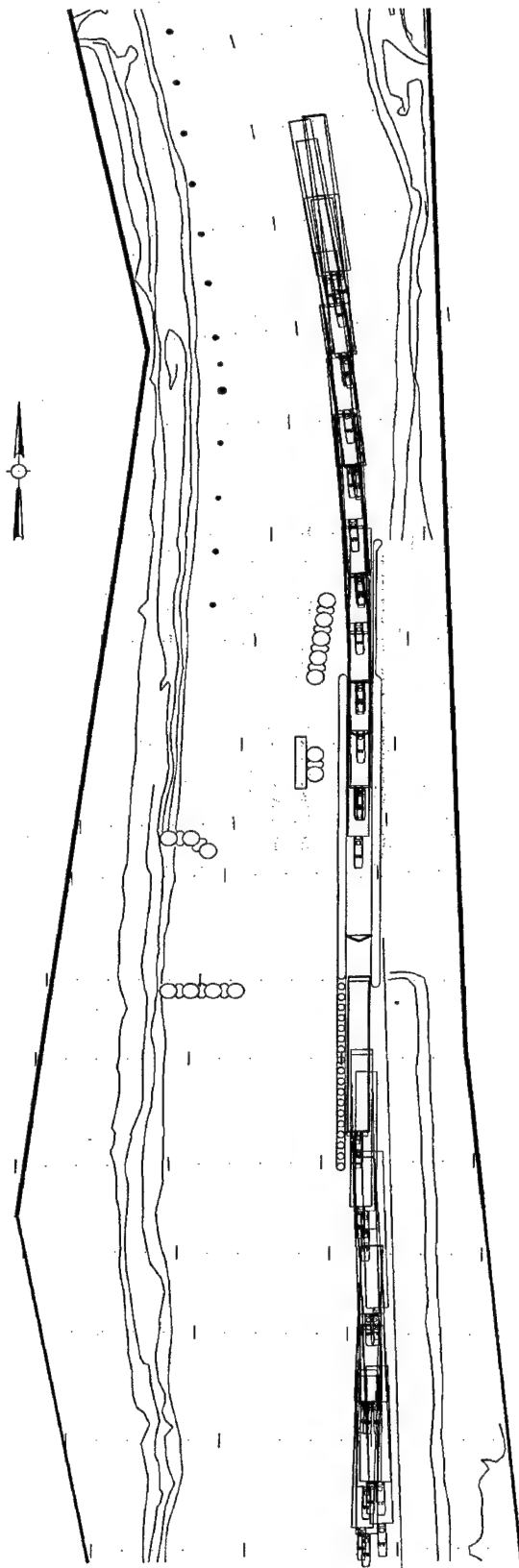
MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPBOUND TOW PATHS

MULTIPLE RUNS  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 3  
DISCHARGE: 25,000 CFS  
TAILWATER EL: 768.3 FT

LEGEND

- 70-FT X 705-FT 6-BARGE TOW
- 35 FT X 195 FT WORK BARGE
- ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM



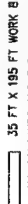


MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
DOWNBOUND TOW PATHS  
MULTIPLE RUNS THROUGH LOCK  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 3  
DISCHARGE: 25,000 CFS  
TAILWATER EL: 768.3 FT

LEGEND



70-FT X 705-FT 6-BARGE TOW



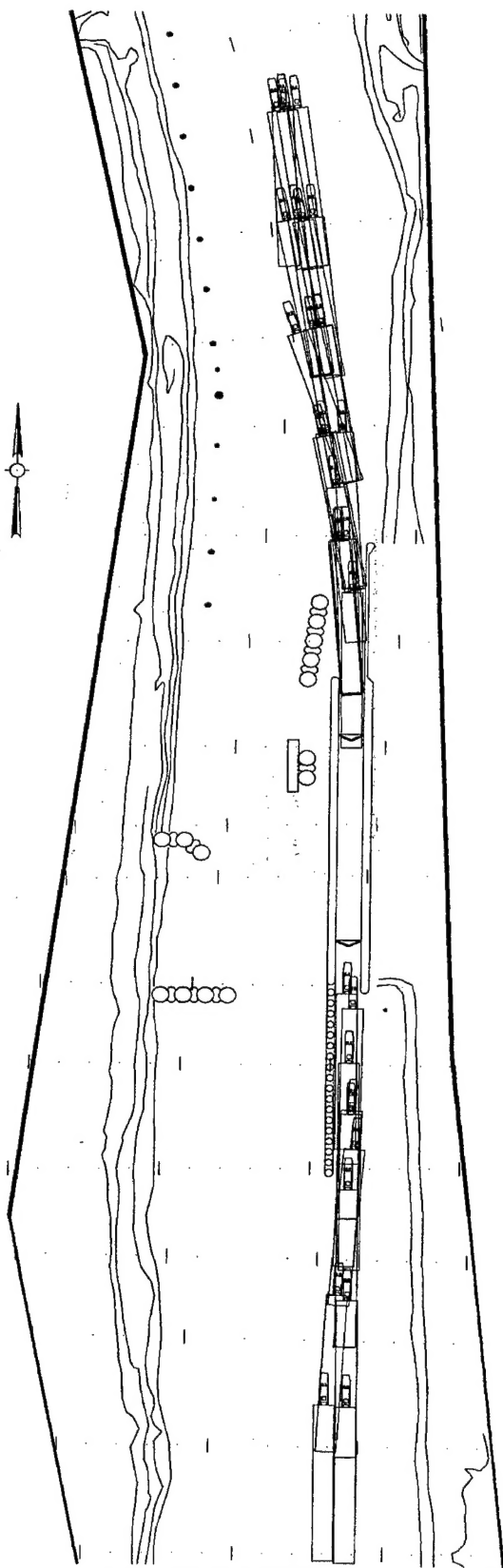
35 FT X 195 FT WORK BARGE

ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

SCALES





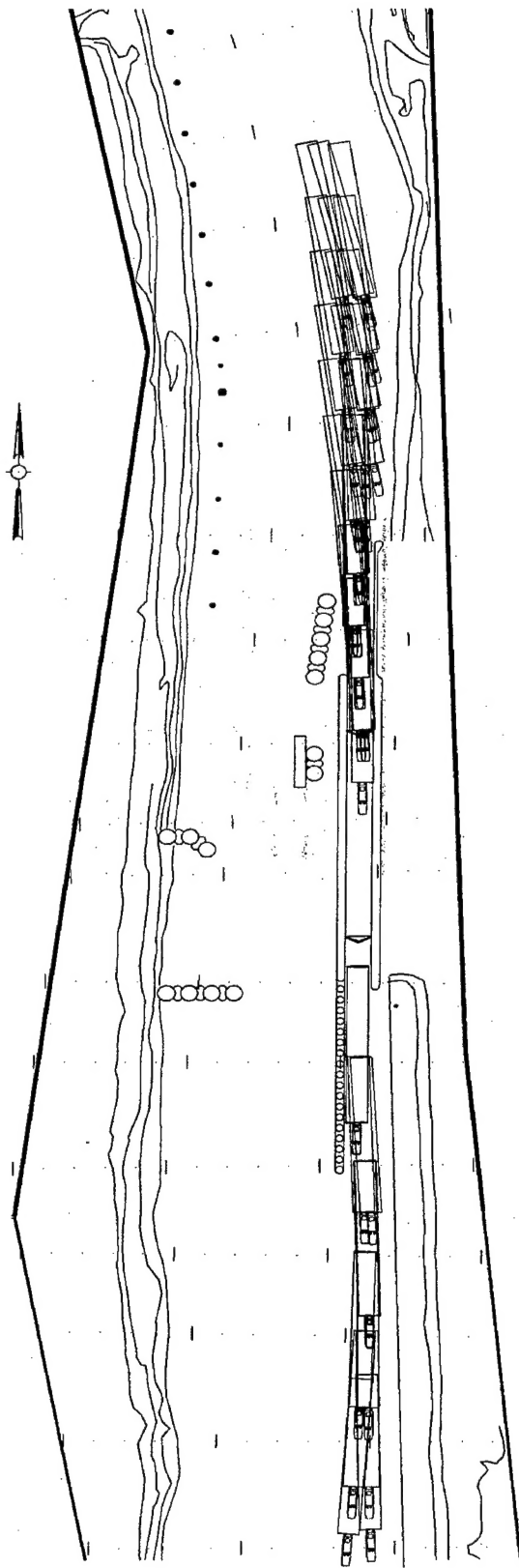


MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPBOUND TOW PATHS  
MULTIPLE RUNS THROUGH LOCK  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 3  
DISCHARGE: 25,000 CFS  
TAILWATER EL: 768.3 FT



LEGEND

- 70-FT X 705-FT 6-BARGE TOW
- 35 FT X 195 FT WORK BARGE
- ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM




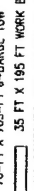
MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER

DOWNBOUND TOW PATHS

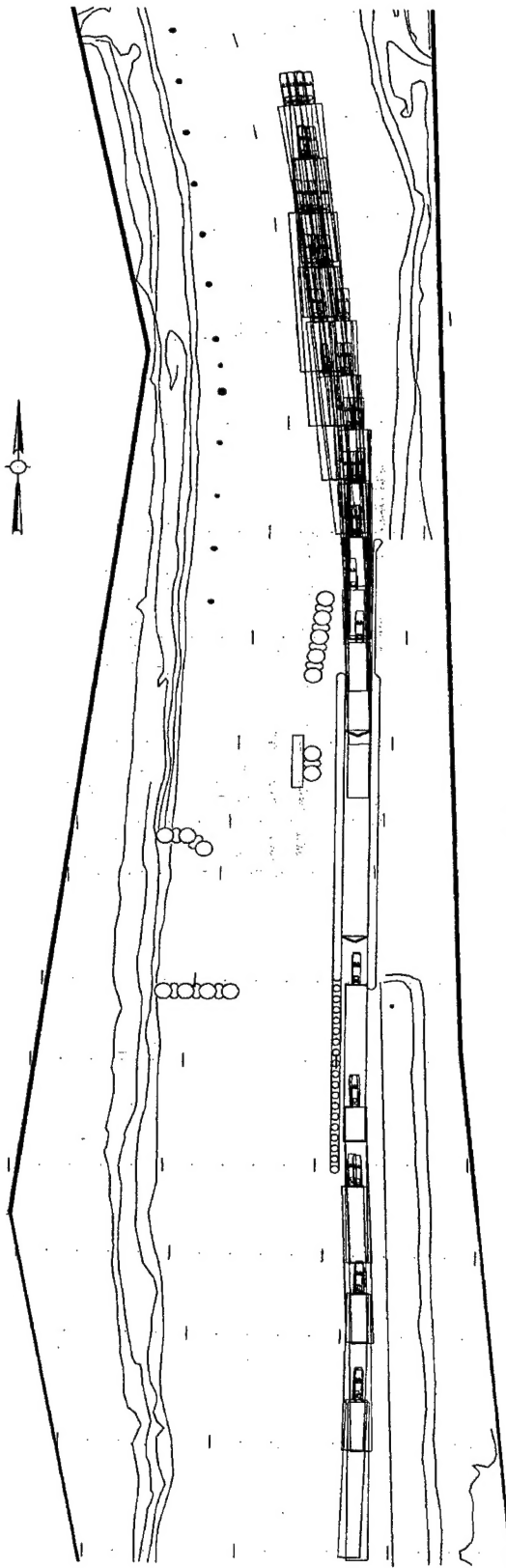
MULTIPLE RUNS THROUGH LOCK  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 3

DISCHARGE: 51,800 CFS  
TAILWATER EL: 774.4 FT

LEGEND

-  70-FT X 705-FT 6-BARGE TOW
-  35-FT X 195-FT WORK BARGE
- ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO OHIO RIVER DATUM

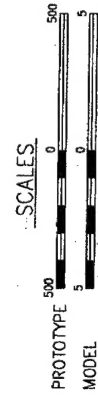




MODEL STUDY OF  
GRAY'S LANDING LOCK AND DAM  
MONONGAHELA RIVER  
UPBOUND TOW PATHS  
MULTIPLE RUNS THROUGH LOCK  
FIRST STAGE OF DAM COFFERDAM  
CONSTRUCTION SEQUENCE - PHASE 3  
DISCHARGE: 51,800 CFS  
TAIL WATER EL: 774.4 FT

LEGEND

- 70-FT X 705-FT 6-BARGE TOW
- 35 FT X 195 FT WORK BARGE
- ALL CONTOURS AND ELEVATIONS ARE  
IN FEET REFERRED TO GMS RIVER DATUM



# REPORT DOCUMENTATION PAGE

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<b>4. TITLE AND SUBTITLE</b> Navigation Conditions at Gray's Landing Locks and Dam, Monongahela River, Hydraulic Model Investigation			<b>5. FUNDING NUMBERS</b>	
<b>6. AUTHOR(S)</b> Ronald T. Wooley				
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b> U.S. Army Engineer Waterways Experiment Station 3909 Halls Ferry Road, Vicksburg, MS 39180-6199			<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b> Technical Report CHL-98-17	
<b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> U.S. Army Engineer District, Pittsburgh Pittsburgh, PA 15222-4186			<b>10. SPONSORING/MONITORING AGENCY REPORT NUMBER</b>	
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<b>12a. DISTRIBUTION/AVAILABILITY STATEMENT</b> Approved for public release; distribution is unlimited.			<b>12b. DISTRIBUTION CODE</b>	
<b>13. ABSTRACT (Maximum 200 words)</b> <p>To maintain navigation on 40 miles of the Monongahela River between Maxwell and Morgantown Locks and Dams, construction of a new lock landward of the existing Lock 8 has been proposed, along with construction of a new lock and dam at river mile 82.2 in the vicinity of Gray's Landing, PA. The new structure at Gray's Landing will consist of an 84-ft-wide by 720-ft-long lock located along the right descending bank and a fixed crest dam. A comprehensive model study was considered necessary to investigate conditions that could be expected with the proposed design and to develop modifications required to ensure satisfactory navigation conditions. The effects of various plans and modifications on water-surface elevations and current directions and velocities were studied, as were the effects of the resulting currents on model towboat and tow behavior.</p>				
<b>14. SUBJECT TERMS</b> Gray's Landing Locks and Dam      Monongahela River Hydraulic model                      Navigation conditions			<b>15. NUMBER OF PAGES</b> 198	
			<b>16. PRICE CODE</b>	
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